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On the Age of the Upper and Middle Deinosaur-Deposits at Tendaguru, Tanganyika Territory.

By F. L. KITCHIN, SC.D., PH.D., F.R.S.

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I. INTRODUCTION.

IN a paper dealing principally with the question of the age and relationships of some Lower Cretaceous bivalve-shells found at Malone, in Texas, I discussed briefly the distribution of those sublittoral Neocomian deposits that are well characterized by the presence of certain *Trigoniae* of southern facies.[1] It was shown that traces of this Neocomian fauna, revealing a general community chiefly by the widespread occurrence of these peculiar groups of *Trigonia*, unknown in the European area, had been found in different latitudes, both in the eastern and western hemispheres, indicating that there had been northward dispersal along the area of the present American continent from Patagonia to Texas, and in the eastern hemisphere from South Africa to the north-west Himalayan border. Some evidence of the same faunal fácies had also been found in New Caledonia. I pointed out that the faunas of these southern Lower Cretaceous *Trigonia* beds of different regions had been misinterpreted again and again, and that their representatives found in Texas, in South Africa, and in Cutch had been thought by some investigators to be of Jurassic age.

Incidental reference was then made to the related *Trigonia* beds in Tanganyika Territory (formerly German East Africa). I stated that the species of Mollusca of Neocomian age found there had been correctly interpreted by the late G. Müller and by Professor E. Krenkel, but that confusion and error had afterwards been introduced by the treatment of some of these fossils by E. Hennig, J. Zwierzycki, and E. Lange.[1] The so-called "*Trigonia smeei*" Bed exposed near Tendaguru, a marine sandy and conglomeratic series about 65 feet in thickness, situated immediately below the Upper Saurian Bed and above the Middle Saurian Bed of the German classification, had been reported by the German investigators to contain Kimmeridge and Tithonian ammonites, but also bivalve-shells of Neocomian (Uitenhage) type. Lange had stated definitely that in addition to *Gervillia dentata* Krauss (Neocomian in South Africa) and the abundant shells ascribed by him to *Trigonia smeei* J. de C. Sow. (Neocomian in Cutch), the specimens from the Nkundi Stream recorded by Müller as *Trigonia ventricosa* Krauss, and the species from Matapua determined by Krenkel as *Eriphyla herzogi* Goldfuss and *Seebachia bronni* Krauss (all Neocomian in South Africa), should also be referred to the "*Trigonia smeei*" Bed; thus they belonged at the latest to a Tithonian age, according to Lange's and Zwierzycki's reading of the evidence provided by the ammonites, not to the Neocomian, as a comparison of these bivalves with those of the Uitenhage Beds (late Valanginian) might seem to show. "*Seebachia bronni* Krauss, *Gervillia dentata* Krauss, *Astarte herzogi* Krauss, and *Trigonia ventricosa* Krauss occur in German East Africa with typical Jurassic cephalopods, just as they do in the Uitenhage Series in company with Cretaceous ammonites. Thus in these species we are dealing with long-lived forms little suited for the determination of age."[2]

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[1] F. L. Kitchin, "The So-called Malone Jurassic Formation in Texas," GEOL. MAG., 1926, pp. 454–69.

Several considerations seemed to me to show the unsoundness of this quoted statement. In the first place, these representatives of the Neocomian Uitenhage fauna include specialized forms like *Trigonia ventricosa*, belonging to a section of the genus (the Scabrae) never yet found in beds older than Neocomian in other districts; and *Seebachia*, a peculiar Astartid derivative with fluted teeth and posterior area, known elsewhere only in Neocomian strata and certainly not showing a type of shell likely to have had more than a short persistence. *Eriphyla herzogi* is elsewhere only known from the late Valanginian Uitenhage Beds[3]; and a very closely related form which occurs in Cutch, in association with Trigonias of the Cretaceous sections Scabrae and Pseudo-quadratae, is also certainly of Lower Cretaceous age.

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[1] Op. cit., p. 468.

[2] E. Lange, "Die Brachiopoden, Lamellibranchiaten und Anneliden der Trigonia Schwarzi-Schicht, nebst vergleichender Übersicht der Trigonien der gesamten Tendaguruschichten." In "Wissenschaftliche Ergebnisse der Tendaguru-Expedition, 1909–12," *Archiv für Biontologie*, Band iii, Heft 4, p. 283, Berlin, 1914.

[3] The age of the marine beds of the Uitenhage Series has been determined by means of the ammonites found in them. F. L. Kitchin, "The Invertebrate Fauna and Palaeontological Relations of the Uitenhage Series," *Ann. S. Afr. Mus.*, vol. vii, part ii, 1908, pp. 25–39. L. F. Spath, "On the Ammonites of the Speeton Clay and the subdivisions of the Neocomian," GEOL. MAG., 1924, p. 86.

In the second place, the *Trigoniae* of the *T. smeei* group, which occur in great numbers in Cutch, just as in the Tendaguru district, are associated in India with species (of the Scabrae and Pseudo-quadratae) which show clearly their Lower Cretaceous age.[1] There was also to be borne in mind the fact that Lange had recorded the rare occurrence of his "*Trigonia smeei*" also in the admittedly Neocomian *Trigonia schwarzi* Bed, overlying the Upper Saurian Bed of Tendaguru, while Professor Hennig had stated that it occurs there by no means rarely.

In the third place, the ammonites of Jurassic age found in the "*Trigonia smeei*" Bed, determined as Kimmeridge and Tithonian forms, appeared in Dr. Spath's opinion only to comprise Kimmeridge species,[2] so that the contention of the German investigators that the Tendaguru Series gives a complete representation upwards from Kimmeridge or earlier Jurassic, and an unbroken passage into the Neocomian, seemed to receive no support from the palaeontological data. Indeed, the evidence, as I was able to read it, pointed to a break of great magnitude and indicated the likelihood that there occurred at some point a gap in the series as great as between Kimmeridge and Neocomian. I expressed the opinion that something had gone seriously amiss either in the collecting or recording, and suggested the probability that the base of the local marine Neocomian series of Tendaguru rests upon Kimmeridge beds at some level in the so-called *Trigonia smeei* Bed. This suggested interpretation, it must be admitted, left unexplained how there could be deinosaurs in the Middle Saurian Bed, underlying the "*T. smeei*" Bed, identical with some of those in the Upper Saurian Bed above it, as shown by the German authorities. Even if some lower part only of the "*T. smeei*" Bed were to prove to be of Kimmeridge age, the remainder being Neocomian, the difficulty of reconciling the widely different age of these two Saurian beds with the identity of their fossil contents would remain as great as before. I did not, however, enter into a discussion of these matters in the course of a brief reference that was subordinate to the main subject of my paper; but it must be admitted that the suggestion was too hastily made, and that a careful consideration of the facts shows that it cannot be upheld.

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[1] There are several forms in the *Trigonia smeei* group, exhibiting similar evolutionary degeneration, and these are not to be swept together into the one species *T. smeei*, as thought by Lange. Their relations will be discussed below.

[2] L. F. Spath, "Ammonites and Aptychi," in J. W. Gregory (and others), "The Collection of Fossils and Rocks from Somaliland made by Messrs. B. N. K. Wyllie, B.Sc., F.G.S., and W. R. Smellie, D.Sc., F.R.S.Ed.," part vii, *Mon. Geol. Dept. Hunterian Museum, Glasgow University*, i, Glasgow, 1925, p. 159.

These criticisms soon called forth vigorous replies from Professor E. Hennig and Dr. W. O. Dietrich,[1] whose papers, in turn, by the nature of the contentions put forward in them, invited a rejoinder. At that time the British Museum Expedition of 1924, engaged in a search for saurian remains at Tendaguru, had suffered a set-back by the untimely death of Mr. W. E. Cutler in August, 1925, and had apparently not made any contribution to our knowledge of the geological age of the deinosaurs embedded in the Middle and Upper Saurian deposits.[2] The difficulty still remained : the Upper Saurian Beds, originally determined by the German workers as of Lower Cretaceous (Wealden) age, had been found to yield not only the same genera but some of the actual species of deinosaurs found in the Middle Saurian Beds, of supposed Lower Kimmeridge age. The attempt had been made to lessen this discrepancy by placing the Upper Saurian Beds at the top of the Jurassic system instead of in the Lower Cretaceous. Thus, Dr. Dietrich so far departed from the original correlation as to range them with the Purbeck, laying stress on a comparison of the vertebrate land-fauna with that found in the Morrison Formation of North America.[3] This correlation, he thought, received support from Dr. G. G. Simpson's work on fossil Mammalia, favouring a Jurassic age for the Morrison fauna. Professor Hennig went so far as to say that, as regards the Upper Saurian Beds, identification with the Morrison Beds provided a stratigraphical foundation which in value did not fall short of that based on a comparison between ammonite deposits.[4] But even if a correlation of the Upper Saurian Beds with the Purbeck were to be accepted, and its soundness was by no means proved, the difficulty of allowing a time-range for the specialized deinosaurs so long as from Lower or even Middle Kimmeridge to Purbeck seemed still so great as to point to some fault in the correlations adopted. One of the main tasks of the British Museum Expedition, it was hoped, would be to attack this fundamental question from a stratigraphical standpoint, endeavouring first to obtain evidence for a revised correlation of the associated marine strata, primarily the "*Trigonia smeei*" Beds. This, surely, was a quest of more value than the continued collecting of bones of so doubtfully determined geological position, or the attempt to settle the question of age by a comparison of the vertebrate land-fauna with that of the Morrison Beds, a freshwater formation lacking any certain means for accurate correlation with a standard succession based on marine faunas. There was reason to fear that the Expedition might have difficulty in obtaining good or plentiful deinosaur-material. It had been reported in 1914 that the work of the German Expedition had been so thorough that the deinosaur-deposits had been practically worked out in their more accessible parts.[1] The geological problem, however, was one of such importance that its early solution was to be expected as one of the first results of the work undertaken by the British Museum.

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[1] W. O. Dietrich, "Das Alter der Trigonienschichten am Tendaguru," *Centralbl. für Min.*, etc., 1927, p. 59. E. Hennig, "Die Altersfragen der Tendaguru-Schichten im südlichen Deutsch-Ostafrika," ibid., p. 64.

[2] F. W. H. Migeod, "The Dinosaurs of Tendaguru," *Nature*, 26th February, 1927, p. 320.

[3] Op. cit., p. 63.

[4] E. Hennig, op. cit., p. 68.

The appointment of Dr. J. Parkinson in the spring of 1927 to superintend the continued work of the British Museum Expedition opened a new chapter in the progress of the expedition's activities, and strengthened the expectation that these pressing questions would very soon be settled. I therefore refrained from preparing any reply to Professor Hennig's and Dr. Dietrich's papers, believing that the solving of the puzzle would be a comparatively easy matter for a geologist actually working at Tendaguru. Now, after eighteen months, we learn from an official publication of the British Museum[2] that this problem, so full of confusion and contradiction, has not yet been clarified by new evidence, and that it still remains unsettled. The question of the age of these deinosaurs is of such wide interest that I venture at this stage to offer an interpretation based chiefly on the evidence of the marine fossils obtained from the "*Trigonia smeei*" zone by the German Expedition. This may perchance become confirmed when the materials and records obtained by the British Museum Expedition have been examined in greater detail.

II. Some Criticisms of Previous Interpretations.

The important monographs in which the first detailed results of the German Tendaguru-Expedition of 1909–12 were made known[3] attracted comparatively little attention in England, no doubt because of the outbreak of war at about the time of their publication. I myself at that time read Professor Hennig's contribution entitled *Beiträge zur Geologie und Stratigraphie Deutsch-Ostafrikas* with great interest, as well as Zwierzycki's account of the cephalopods. Both of these were issued separately in 1913, and were circulated in this country much earlier than the remainder.

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[1] W. Branca, "Kurzer Bericht über die von Dr. Reck erzielten Ergebnisse im vierten Grabungsjahre, 1912," *Archiv für Biontologie*, Band iii, Heft 1, 1914, p. 62.

[2] J. Parkinson, "The Dinosaurs of Tendaguru," *Natural History Magazine*, vol. i, No. 8, October, 1928, p. 275.

[3] "Wissenschaftliche Ergebnisse der Tendaguru-Expedition, 1909–1912," Teil I, *Archiv für Biontologie*, Band iii, Heft 1, Berlin, 1914. Contains papers by W. Branca and W. Janensch of a general character, and two on the deinosaurs. Teil ii, ibid., Band iii, Heft 3, 1914, comprising E. Hennig, "Beiträge zur Geologie und Stratigraphie Deutsch-Ostafrikas," p. 1 (first issued separately in 1913); H. von Staff, "Beiträge zur Geomorphogenie und Tektonik Deutsch-Ostafrikas," p. 73; W. Janensch, "Die Gliederung der Tendaguru-Schichten im Tendagurugebiet und die Entstehung der Saurierlagerstätten," p. 225; W. Janensch, "Über Torfmoore im Küstengebiete des südlichen Deutsch-Ostafrika," p. 263. Teil iii, ibid., Band iii, Heft 4, 1914, comprising W. Janensch and E. Hennig, "Tabellarische Übersicht der Fundorte wirbelloser Fossilien im Arbeitsgebiete der Tendaguru-Expedition," p. 1; J. Zwierzycki, "Die Cephalopodenfauna der Tendaguruschichten in Deutsch-Ostafrika," p. 7 (first issued separately in 1913); W. O. Dietrich, "Die Gastropoden der Tendaguruschichten, der Aptstufe und der Oberkreide im südlichen Deutsch-Ostafrika," p. 97; E. Hennig, "Die Invertebraten-Fauna der Saurierschichten

Apart from the uppermost beds entering into the solid geology of the region, the Makonde Formation, shown to the north of the Tendaguru district to comprise Aptian, and beds displaying an Urgonian facies, the series in the Tendaguru neighbourhood exhibits the following succession, as set forth by Professor Janensch :—

	Thickness in metres, about
Upper Sandstone-zone with *Trigonia schwarzi* . .	5
Upper Saurian Beds, chiefly sandy marls . . .	40
Middle Sandstone-zone with *Trigonia smeei* . .	20
Middle Saurian Beds	15
Lower Sandstone-zone or *Nerinea*-zone . . .	25
Lower Saurian Beds	20 or more.

The strata lie almost horizontally, and are not disturbed or faulted. Those below the Upper Saurian Beds are exposed in the stream-gullies on the margin of the plateau to the immediate west and south-west of Tendaguru Hill.

The whole of this succession was termed the Tendaguru Series. Professor Janensch referred its two uppermost members to the Neocomian ; the underlying " *Trigonia smeei* " zone was considered by him to represent Upper Kimmeridge-Tithonian ; the Middle Saurian Beds were placed as Kimmeridge ; while the two lower members were tabulated as " Malm ", without narrower designation. Zwierzycki found the *Trigonia schwarzi* zone to yield cephalopods indicating the presence of Valanginian, Hauterivian, and possibly also Barremian, but with some apparent intermingling. He tabulated the Upper Saurian Beds as Wealden ; the " *Trigonia smeei* " zone as Upper Kimmeridge-Tithonian ; the Middle Saurian Beds as Lower Kimmeridge (Sequanian) ; the *Nerinea* zone as Oxford ; and the Lower Saurian Beds as Kellaways. Lange made the " *T. smeei* " zone Upper Tithonian.

It is unnecessary here to occupy space by a detailed account of the results of the German Expedition. It will suffice to discuss those points which have the most direct bearing on the determination of the age of the Middle and Upper Saurian deposits. An admirable summary of the work of the German investigators, based upon the

am Tendaguru," p. 155 ; E. Lange, " Die Brachiopoden, Lamellibranchiaten und Anneliden der Trigonia Schwarzi-Schicht, nebst vergleichender Übersicht der Trigonien der gesamten Tendaguruschichten," p. 187 ; E. Hennig, " Die Fischreste unter den Funden der Tendaguru-Expedition," p. 291. Since the war, the issue of the further detailed results of the Expedition's work has been resumed ; *Palaeontographica*, Supplement vii, is entirely devoted to these important papers, the publication of which is still in progress.

Tendaguru monographs cited above, was published by Professor C. Schuchert[1] in 1918. I have studied the original monographs with great care and find Professor Schuchert's account to be lucid, accurate, and judicial. Moreover, he contributed some pertinent and suggestive observations when discussing this troublesome question of correlation.

In these earlier works the German authors were in general agreement in regarding the Upper Saurian Beds as of Neocomian or Wealden age. It may be gathered from a perusal of the monographs, though it does not seem to be explicitly stated, that the opinion that the Middle Saurian Beds are of Jurassic age was not formed while the field-work was in progress. This view seems to have been first adopted as a result of the work done afterwards by Zwierzycki, who determined the ammonites ascribed to the "*Trigonia smeei*" zone as Kimmeridge and "Tithonian" forms. It was at once inferred that the zone must be dated by means of these ammonites and that the Middle Saurian Beds must correspondingly conform with this result and be relegated to the Kimmeridge, or Lower Kimmeridge according to Zwierzycki himself. Lange seems, in consequence, to have been at great pains to bring the results of his investigation of the lamellibranchs into line with this classification. His elaborate discussion of the matter contains much special pleading, and one feels that if Lower Cretaceous ammonites had been found in the "*T. smeei*" zone his task would have been very much easier. It is certain that in that event he would have had no difficulty in producing ample supporting evidence from the bivalves of that zone, without the necessity for the laboured and lengthy discussion into which he entered in order to remove evidence that spoke against the correctness of the new interpretation.

In adopting this correlation with such assurance and unanimity, the authors of the Tendaguru monographs (1914) seem to have been influenced by two firm convictions: firstly, that the ammonites stated to be found in the "*Trigonia smeei*" zone must be indigenous, and secondly, that the whole Tendaguru Series is the result of a continuous sedimentation, without any break of appreciable magnitude in the stratigraphical succession, thus bridging over the passage from Jurassic to Lower Cretaceous. There is little information in the monographs regarding the mode of occurrence of the ammonites in the "*Trigonia smeei*" zone, or indeed as to the actual position in which they occurred in the zone. It would be interesting to know the relative positions in the zone in which the different species were found; and whether these ammonites were encased in nodules; and if not, to what extent they showed signs of wear and tear. To judge from the descriptions, the "*Trigonia smeei*" zone is a type of shallow-water deposit formed under somewhat turbulent conditions, unlikely to yield contemporaneous ammonites. I shall return to this point in the following section of this paper. Although so much depends upon this discovery of Kimmeridge ammonites in an unexpected position, we are left without particulars that might possibly have helped to render more easy the acceptance of this age-determination of the zone. Apart from this, the authors used every argument, plausible and not plausible, that could possibly be adduced in support of their interpretation, by which the Middle Saurian Beds and part of the " *T. smeei* " Beds became assigned to the Kimmeridge.

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[1] C. Schuchert, "Age of the American Morrison and East African Tendaguru Formations," *Bull. Geol. Soc. America*, vol. xxix, 1918, p. 245.

The claim made by the authors of the monographs that the rocks comprised in the Tendaguru Series represent an unbroken succession without gaps, from pre-Kimmeridge to Aptian, has always appeared to me to be an extraordinary one. Viewed in the light of general considerations, its soundness seems inherently most improbable. To those who have studied carefully the zonal constitution of shallow-water deposits in other regions, belonging to any geological system, the claim must seem surprising in the highest degree. The situation of the Tendaguru Beds on the margin of a continent; the sub-littoral and littoral character of the marine faunas; the petrographical composition and physical characters of the strata, often showing the influence of strong current-action; and the repeated replacement of purely marine conditions by a fluctuating salt-lagoon, estuarine, or perhaps even fluviatile facies: all these considerations would justify an uncompromising scepticism. If we turn to the concrete evidence of the palaeontological data actually obtained, this doubt received such ample support as to be turned into positive disbelief.

Among the Jurassic cephalopods obtained in the Tendaguru Series the latest, so far as we know, are Kimmeridge in age, and for the most part not, apparently, of later time than the Middle Kimmeridge of Dr. Spath's classification. The suggestion that any later zone is represented can only be made with doubt. Since his passing reference to the age of these ammonites in his paper of 1925, Dr. Spath has thrown some doubt on the exact position of one of them, *Hildoglochiceras kobelli* (Oppel).[1] In his current monograph on the ammonites of Cutch he refers it to the " Upper Kimmeridgian ? ". A doubt concerning the exact age of this ammonite-species does nothing, however, to help the theory that there is complete representation of the higher Jurassic rocks at Tendaguru. So far as evidence is concerned, there still remains a whole series of Upper Jurassic zones represented there only in theory, and we have been told of no changes in the fauna of the " *Trigonia smeei* " zone, when traced in upward succession within the zone, which support the theory in any way. If we accept a Kimmeridge age for the zone, or even a Portland age for its upper part (which is unsupported by definite evidence), we must still believe that " *Trigonia smeei* " then ceased to exist in this area, but by some extraordinary chance resumed life there in Valanginian time without having undergone any evolutionary change. Such a case does not belong to the realm of serious geology or palaeontology. We look in vain for proof of any representation of the Portland zones (proper), the Tithonian zones (proper) and " Lower Berriasian " in the highest Jurassic position, and of the lowest part of the Cretaceous system (" *boissieri* zone "). If Jurassic rocks are in reality present above the Middle Saurian Beds, the point to be ascertained is the level in the series at which the junction occurs between the Jurassic and Cretaceous beds, so widely different in age.

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[1] L. F. Spath, " Revision of the Jurassic Cephalopod Fauna of Kachh: Part II," *Palaeontologia Indica*, New Series, vol. ix, Mem. No. 2, 1928, p. 159.

The remarkable conclusion that there is present in the Tendaguru Series an unbroken succession of beds, and that a standard section for the complete passage from Jurassic to Cretaceous is thereby provided in East Africa, involves the acceptance of anomalies and contradictions perhaps almost without precedent in serious geological work. This reading of the section called for the most cautious and rigid checking before its publication. Yet these surprising results were put forward precipitately, with the utmost assurance and without reservation of any kind. Little time seems to have been allowed in which to weigh the awkward consequences. I need only quote two statements, taken from Professor Hennig's work, entitled *Beiträge zur Geologie und Stratigraphie Deutsch-Ostafrikas.*[1] " In der Zeit vom ältesten Dogger bis zum Abschluss der unteren Kreide hat das deutsch-ostafrikanische Gebiet keine vollständige Trockenperiode erlebt . . ." (p. 3). During that long stretch of geological time no emergence had taken place. Then, as a declaration that knowledge of the geological succession in German East Africa was final and absolute, we are told (p. 15) that since the succession was ascertained by direct observation and was not built up by combination, therefore if there should appear to be any want of agreement between the fossils found and the correlations adopted, our views as to the stratigraphical age of the faunas or their individual representatives must be made to fit in with this actual scheme of ascertained facts. Further, we are told that in considering the faunal relations of German East Africa and other geologically allied regions, the results obtained in those countries must be weighed against one another in testing their validity, and if necessary, the conclusions arrived at elsewhere must be corrected by means of the certain knowledge obtained in German East Africa, not the reverse. A paraphrase-translation scarcely does justice to this passage, which should be read in its original form. Despite the criticisms, such as Professor Schuchert's, that have appeared since 1913, Professor Hennig evidently still maintains this claim to final knowledge, for he quotes the above,[2] as though it were an ultimatum, in his paper of 1927 already cited. He remarks that he cannot see how he could strengthen these words of his written in 1913, and all readers are likely to agree with him on that point. Yet the very strength of these assertions and the form in which they are made, and particularly the hint as to a possible appearance of discrepancy between the fossils found and the correlations adopted, seem to me to suggest a basis of unsoundness.

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[1] *Archiv für Biontologie,* Band iii, Heft 3, 1914, pp. 3, 15 (first issued separately in 1913).

[2] *Centralbl. für Min.,* etc., 1927, p. 65.

Throughout the monographs there are to be found repeated references to the supposed junction-beds or passage-beds (Grenzschichten) between the Jurassic and Cretaceous systems, and it is evident from a remark in the paper just cited (p. 69) about " the old Janus-head of the Jurassic-Cretaceous junction-beds " that Professor Hennig is still of the opinion that the passage strata are present at Tendaguru. Lange had written in 1914 : " this is the first section drawn up with certainty of junction-beds between the Jurassic and Cretaceous systems on the African continent."[1] But we look in vain for proof of this in the series described. The passage cannot lie in the *Trigonia schwarzi* Beds, which are admittedly not older than Valanginian. If we look at the next set of marine strata lower in the series, the " *Trigonia smeei* " sandstones, and for the moment, for the sake of argument, regard the ammonites which are said to occur there as indicating the geological position of those sandstones, there is nothing definitely later than Kimmeridge, far enough distant from the top of the Jurassic system. The assignment of a part of these sandstones to the Lower Tithonian, in the classification given by some of the German investigators, leaves us in doubt as to the exact meaning. It is well known that the term Tithonian has sometimes been used to comprise beds of Kimmeridge age, as well as certain strata much nearer to the top of the Jurassic system. While Lange tabulated the " *Trigonia smeei* " zone as Upper Tithonian, Dietrich has ascribed some upper, undefined part of it to the Lower Tithonian[2]; but in his paper of 1927, a year later, he correlated the zone partly with the Kimmeridge and partly with the Portland.[3] This still keeps these marine sandstones well below the top of the Jurassic system, even if admitted as a sound correlation ; and no plausible claim could be made, on the evidence available from the marine fossils, that Tithonian zones proper, of post-Portland age, have any representation.

In his paper on the corals just cited (1926), Dr. Dietrich stated that the *Trigonia* beds of the Oomia Group in Cutch, shown to be closely allied to the " *T. smeei* " Beds of Tendaguru by the presence of the similar, abundantly occurring Trigonias, are of Tithonian age. He mentions as supporting evidence that Dr. Spath has placed the lower part of the Oomia Beds in the zone of *Perisphinctes contiguus* (Tithonian), but he ignores the fact that, assuming a true association of the ammonites with the *Trigoniae* in each of these districts, this would not bring the Oomia *Trigonia* beds into correlation with the " *T. smeei* " zone of Tendaguru. But this mode of using a comparison with the *Trigonia* beds of Cutch is quite inadmissible and misleading, because those beds are situated in a part of the Oomia series of strata from which Jurassic ammonites have never been obtained; they occupy a higher position and are not of Tithonian age. Indeed, the presence in them of *Trigoniae* of the *T. ventricosa* group of the Scabrae, and of the section Pseudoquadratae, alone suffices to show their Lower Cretaceous age. It is curious that Dr. Dietrich should take pains to state that the *Trigonia*-bearing beds are in Lower Oomia strata below the plant-beds, since it was made clear by Blanford, who had first-hand knowledge, that they occur intercalated in the plant-bearing beds and also above them.[1] Lange's remarks on the *Trigonia* beds of the Oomia Group are equally prejudiced and uncritical, and his whole mode of argument invites distrust.[2]

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[1] *Archiv für Biontologie*, Band iii, Heft 4, 1914, p. 191.

[2] W. O. Dietrich, " Steincorallen des Malms und der Unterkreide im südlichen Deutsch-Ostafrika," *Palaeontographica*, Suppl. vii, Reihe ii, Teil 1, Lief. 2, 1926, p. 51. Also, " Über eine dem mittleren Sauriermergel am Tendaguru äquivalente, rein marine Kimmeridgebildung in Mahokondo, Deutsch-Ostafrika," ibid., Reihe ii, Teil 1, Lief. 1, 1925, p. 22.

[3] *Centralbl. für Min.*, etc., 1927, p. 63.

If we still assume, for the sake of argument, that the " *Trigonia smeei* " zone is Jurassic, we are driven to conclude that the supposed passage to the Cretaceous system must lie wholly in the Upper Saurian Beds. But what scrap of evidence have these beds yielded for a certain determination of age? We may now consider this briefly.

An account of the invertebrate fossils obtained from the Upper Saurian Beds was given in 1914 by Professor Hennig.[3] He classified the deposit as Wealden; and indeed the close association with the Valanginian beds above appears alone to be sufficient justification for this. The invertebrate forms occurring here were reported to be a *Mytilus* comparable with *M. galliennei* d'Orbigny; shells of *Cyrena* specifically undetermined, but stated to be, in Professor Hennig's opinion, identical with those found in similarly large numbers in the Middle Saurian Beds; and two gasteropods, *Physa tendagurensis* Dietrich and a doubtful *Bythinia*. There is nothing here to show that the deposit is older than Neocomian. It is developed in a facies approaching that of the Wealden of Europe, but showing a more brackish-water character and to a less extent the influence of purely freshwater conditions.

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[1] W. T. Blanford, " Note on the geological age of certain groups comprised in the Gondwana Series of India," *Records Geol. Surv. Ind.*, vol. ix, part iii, 1876, p. 81. " Palaeontological Relations of the Gondwana System," ibid., vol. xi, part i, 1878, p. 119. *A Manual of the Geology of India*, 1st ed., part i, 1879, p. 259.

[2] E. Lange, op. cit., 1914, pp. 283, 284.

[3] E. Hennig, " Die Invertebraten-Fauna der Saurierschichten am Tendaguru," *Archiv für Biontologie*, Band iii, Heft 4, 1914, p. 155.

If we turn now to the vertebrates, the closest comparison can be made with those in the Morrison Formation of North America, yielding an allied, though not identical fauna, including large sauropod reptiles. The Morrison Beds, a freshwater series of variable thickness, rest with some degree of unconformity on the Sundance Formation, which is shown by its marine fossils to be a Jurassic series older than Kimmeridge. No marine strata are associated with the Morrison Beds by the help of which they can be correlated accurately. They might be of latest Jurassic or earliest Cretaceous age, and might possibly bridge over that part of geological time; but they have generally been correlated with the Wealden of Europe. Professor Schuchert gave a summary of the views on this question in his paper cited above.[1] Since then, Dr. G. G. Simpson has studied this question of correlation carefully. In his admirable discussion of it [2] he has weighed the evidence provided by the vertebrate fauna, and has paid special attention to the remains of mammals. He concludes that these, in particular, indicate the probability of a pre-Purbeck age, and suggests that the Morrison Formation might be referred to the Kimmeridgian or the Portlandian. He deals judicially with the Tendaguru Series, and its bearing on this question, and thinks that on the whole, the evidence from Tendaguru supports the other data tending to show the Jurassic age of the Morrison Formation. At the same time, Dr. Simpson expresses himself cautiously. " There now appears to be no definite reason for calling it [the Morrison] Cretaceous, although the evidence may not be altogether conclusive and it is perhaps conceivable that this might ultimately prove to be correct " (p. 214).

Dr. Dietrich has seized upon this, and in his paper of 1927 expresses his views on the age of the Upper Saurian Beds at Tendaguru as follows [3]: " The assumption of a Wealden age, held up till now, is based on facies-considerations, not on guide-fossils (see E. Hennig's works). The invertebrate fauna recorded by Hennig and the fish-fauna from the Upper Saurian Bed contain no species which could not occur in the Upper Jurassic. In addition to brackish forms (*Cyrena*, *Mytilus*, small and large !) there occurs also a freshwater gasteropod, *Physa*, besides a single mammalian lower jaw of a Pantothere, family Amphitheriidae. This jaw (like the Pterosaur remains) speaks decidedly for the Jurassic age of the Upper Saurian Bed, the more so as lately the Morrison Beds have been shown by Simpson, from the standpoint of the fossil mammals, to be Portland or Kimmeridge. According to the marine evidence below and above the Upper Saurian Bed there remains for it a time-space of Upper Portland, Purbeck, and, it may be, the *Boissieri* Zone, for neither typical Upper Tithonian ammonites nor forms f the *Boissieri* Zone have been proved in German East Africa. ow the junction can naturally not be drawn through the Upper aurian Bed itself, and it is therefore most natural to place it above, s already Schuchert and Buckman, in 1918, wished to do. Thereby ll three deinosaur-deposits are brought into the Upper Jurassic, nd the deinosaurs themselves become ranged more nearly together a their geological age."

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[1] *Bull. Geol. Soc. America*, vol. xxix, 1918, p. 245.

[2] G. G. Simpson, " The Age of the Morrison Formation," *Amer. Journ. Sci.*, Ser. v, vol. xii, 1926, p. 198.

[3] *Centralbl. für Min.*, etc., 1927, p. 63, footnote.

The effort to bring the deinosaurs of the Middle and Upper Saurian eds more closely together in an age-classification is certainly praiseorthy. But we must inquire whether the facts give stronger astification for lowering the position of the Upper Saurian Beds a the geological time-scale or for raising that of the Middle Saurian eds. Incidentally, it may be remarked that the assignment of a urbeck age to the Upper Saurian Beds does not in any way support he view that the series at Tendaguru is complete from Jurassic o Cretaceous. An extra gap in the series is introduced; for it ould be the merest assumption to say that the Upper Saurian eds bridge over all the time-period between Kimmeridge (or even ower Portland) and Valanginian.

I can see nothing in the palaeontological evidence furnished by he Upper Saurian Beds to show with any certainty that this subivision of the series is older than Neocomian. Amphitheriid nammals were presumably existing in Wealden time. Dr. Simpson's iews on the age of the Morrison Formation are worthy of all onsideration, but can have less weight in determining the age f the Upper Saurian Beds of Tendaguru than the evidence of the ssociated marine beds which, I believe, will enable us to decide this uestion beyond doubt.

So far, I have discussed these matters on the assumption that he German geologists were right in regarding the ammonites found a the "*Trigonia smeei*" zone as indigenous. I have shown that f we allow that assumption, the marine fossils from below and rom above the Upper Saurian Beds provide no evidence for the elief that there is a complete passage, as claimed, from Jurassic o Cretaceous. The Upper Saurian Beds also fail to give support o that idea, and to judge from their palaeontological evidence are s likely to be of Wealden as of Purbeck age. The assumption that he Jurassic ammonites are indigenous also leaves us confronted y the extraordinary difficulty that the Middle Saurian Beds, thus ssigned to a Middle Kimmeridge or Lower Kimmeridge age, ontain a reptilian fauna very intimately related to that of the Jpper Saurian Beds (comprising, in fact, some identical species), or which an age earlier than Purbeck has not been claimed, and n age later than Purbeck is probable.

The settlement of this matter therefore depends on the question vhether the admittedly indigenous bivalve-fauna of the "*Trigonia meei*" zone gives such decisive indications of a geological age lifferent from that inferred from the ammonites as to show that these ammonites are not indigenous. Professor Schuchert put this very question in other words, in 1918, when he wrote[1]: "If the dinosaurs are correctly determined, then all of the invertebrates of the *T. smeei* zone should be reinvestigated to see if some of them can not be referred to the Lower Cretaceous, and so brought into harmony with the evidence of the dinosaurs . . ."

III. THE AGE OF THE SO-CALLED *TRIGONIA SMEEI* ZONE.

If we accept the idea that the ammonites recorded from this zone must be indigenous, it is then necessary to regard the *Trigoniae* as having existed in Kimmeridge time. They admittedly belong to the zone, and by reason of their abundance constitute the most characteristic part of its fauna. They certainly belong to the *Trigonia smeei* group and are closely related both to *Trigonia smeei* J. de C. Sow. itself and to *T. crassa* Kitchin, the two representatives of this striking group in India. *Trigoniae* of this group are so far only known with certainty to occur in the Tendaguru Series, in the *Trigonia* beds of the Oomia Group of the Mesozoic series in Cutch, and in some *Trigonia*-bearing beds north-east of Coconada, on the south-east coast of the Indian Peninsula.[2] They show a prolific, gregarious habit, some of them occurring in such masses as to constitute "pavements" of shells. They have large and conspicuous valves, which are peculiarly characterized by their form and surface-sculpture, so that their presence in any bed could not escape notice. It is therefore a fact most important in the present discussion that in Cutch, in Madagascar, as well as in districts of East Africa apart from Tendaguru, strata of proved Kimmeridge age show no sign whatever of the presence of these Trigonias. If these remarkable and abundant lamellibranchs had been found there, it is certain that their occurrence would have been reported. Let us then examine the bivalves of the "*Trigonia smeei*" zone without the prejudice introduced by the assumption that the ammonites are indigenous in that zone. Let us now allow the possibility that the ammonites may have been derived into the *Trigonia*-sandstones. We shall thereby arrive at a correlation that is in accord with the known facts and is free from inconsistency and contradiction.

In the first place we may examine the lamellibranchs found in this zone by the German Tendaguru Expedition, so far as they have been made known, afterwards considering the few species previously recorded by G. Müller and by E. Krenkel which were also ascribed to the same zone by Lange. It is unfortunate that ange described only the *Trigoniae* obtained by the Expedition rom this zone, and it would be interesting to know something about ie other bivalves which were doubtless also found in these fossili- erous sandstones during the years 1909–12.

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[1] Op. cit., p. 280.

[2] A possibly related form occurring in South America has been discussed by E. Lange, "*Trigonia smeei* Sowerby und ihre horizontale Verbreitung," *Centralbl. für Min.*, etc., 1917, p. 492.

The abundant shells of *Trigonia* described by Lange under the ame *T. smeei* show great variability and instability, both in their rm and sculpture. The same inconstancy was noted by me in ie case of *Trigonia crassa* from Cutch. The true *T. smeei* J. de C. ow.[1] shows a more stable character, and illustrates more clearly, y its growth-stages up to the end of the adolescent period, its erivation from the typical Costatae. The ancestral differentiation f the sculpture on the flank and area, with well-developed marginal nd inner carinae and finer, delicately nodose longitudinal orna- ients on the area, is retained during individual development for longer period than in either of the other forms. In this respect he shells from Tendaguru stand in a position somewhat intermediate etween *T. smeei* and *T. crassa*. *Trigonia crassa* shows the replace- ient of the carinae and the sculpture of the area by simpler con- rescent ridges at an earlier growth-stage. Its shells are more iassive and frequently attain a larger size and greater relative eight of figure than either *T. smeei* or the related Tendaguru form, ange's "*T. smeei*", which is less markedly truncated by a straight teep anterior border than *T. crassa*, but rather more truncated and ith a less pronounced convexity of the anterior border than the rue *T. smeei*, with which it should not be confounded. It seems ossible that more than one offshoot "species" showing closely milar characters of degeneration is present in the "*T. smeei*" one at Tendaguru. This is suggested by the figures given by ange, but would be difficult to prove without the collecting of pecimens with the strictest regard to their position in the zone. ange's treatment of the shells of this group, by which they are wept into one species only, appears to me to be uncritical, as is hown by the separate occurrence and distinct faunal associations f the two species found in Cutch, which Lange regarded as iseparable from the variable form with which he was dealing.

Trigonia smeei is known only from localities in the district of Vagur, in Eastern Cutch. It is less abundant than *T. crassa*, which known in Cutch exclusively from localities, such as Oomia and oonaree, which are on the western side.[2] *Trigonia smeei* is ssociated with a remarkable lamellibranch-fauna characterized hiefly by the abundant occurrence of large conspicuous shells of startid relationship, which show degenerate characters. One of these is *Astarte major* J. de C. Sowerby.[1] With these, among other species, are *Trigonia tenuis* Kitchin, species of *Cucullaea*, a *Seebachia*, a large *Gervillia* closely resembling *G. dentata* Krauss, of the Neocomian Uitenhage Series, and another large *Gervillia* of distinct species. Among the numerous oysters are *Exogyra imbricata* Krauss (Neocomian) and another large exogyrate oyster of Cretaceous type. The morphological position of *T. smeei*, when viewed from the evolutionary standpoint, the manner in which its late adult characters approximate to those occurring at an earlier stage in the ontogeny of *T. crassa*, and the presence of *Seebachia* in this fauna, in addition to species of *Exogyra* which are of Cretaceous and not Jurassic type, are facts sufficing, in my opinion, to show that the fauna is of Lower Cretaceous age, and that it bears a near relationship to the fauna containing *T. crassa*.

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[1] W. H. Sykes, "A Notice respecting some Fossils collected in Cutch by apt. W. Smee, of the Bombay Army" (fossils described by J. de C. Sowerby), *rans. Geol. Soc. Lond.*, Ser. II, vol. v, 1840, p. 715, pl. lxi, fig. 5. F. L. Kitchin, The Jurassic Fauna of Cutch. The Lamellibranchiata, Genus *Trigonia*." *alaeontologia Indica*, Ser. IX, vol. iii, 1903, pp. 40–4.

[2] F. L. Kitchin, op. cit., p. 44.

Trigonia crassa occurs in Western Cutch in great numbers, associated with a bivalve-fauna in several respects distinct from that with which *T. smeei* is found in Wagur. Most noteworthy are Trigonias of the group of *T. ventricosa* (Krauss), of the section Scabrae, and *Trigonia mamillata* Kitchin, of the section Pseudoquadratae, which proclaim unequivocally the Neocomian age of the fauna. There are also large, massive-shelled forms of *Gervillia*, and an abundant *Eriphyla* closely allied to *E. herzogi* (Goldfuss), of the Uitenhage Neocomian beds. This fauna, including also other *Trigoniae*, occurs in coarsely gritty sediments recalling in character the "*Trigonia smeei*" zone of Tendaguru.

The characters of the true *Trigonia smeei*, as well as those of its associated species of *Gervillia*, show less evolutionary advancement than is exhibited by *T. crassa* and its associates. I am, therefore, of opinion that the *T. smeei* fauna occupies a lower horizon than the *T. crassa* fauna, though the character of some of the constituents of the two faunas speaks against a wide separation in age. Neither of these actual assemblages of bivalves has been recognized in the Tendaguru Series, so far as can be judged from the information published, though the presence of a *Trigonia* of the *T. ventricosa* group, and an *Eriphyla* determined as *E. herzogi*, to be noticed below, shows an alliance between the fauna containing *T. crassa* in Cutch and that found below the Upper Saurian Beds at Tendaguru. But it must be remembered that the nature of this co-called *Trigonia smeei* zone, developed there as coarse and false-bedded sandstones and conglomeratic courses, with a sameness in the fauna, so far as we have been told, from bottom to top, points to rapid deposition during a relatively short time-period; and that the underlying and overlying strata, the two main saurian-bearing deposits, were developed in a facies quite different from that of the *Trigonia*-sandstones. The marine succession is so interrupted that the record is only fragmentary, and this is probably also true in Cutch. But he characters of the shells ascribed by Lange to *Trigonia smeei*, as lso the nature of the associated bivalves, must lead us to regard he age of the sandstones in which they occur as not widely different rom that of the beds containing the two related Trigonias in Cutch. In all probability the "*T. smeei*" zone of Tendaguru occupies an ntermediate zonal position, though it is not known for certain hether any of the Trigonias occurring in it represent a stage in a irect lineage from *T. smeei* to *T. crassa.*

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[1] In W. H. Sykes, op. cit., p. 718, pl. lxi, fig. 1 (described in Explanation of plate).

A comparison, therefore, of Lange's "*Trigonia smeei*" with he two closely related species in Cutch speaks unquestionably for he Lower Cretaceous age of the "*T. smeei*" zone. It must not be orgotten also, that Lange recorded the occurrence of a specimen f his *Trigonia smeei* from the Neocomian *Trigonia schwarzi* zone, verlying the Upper Saurian Beds (Locality 31). Its position in eocomian beds there was said to have been determined with ertainty.[1] After this positive statement, unchallenged at the ime, it is with surprise that one reads Lange's later suggestion that ome error may possibly have crept in here.[2] Of course, this ccurrence does not fit in with the scheme of correlations adopted. fter making the suggestion that might help to remove a difficulty, Lange proceeded to say that this, the only occurrence of *T. smeei* nown up to that time in beds higher than Tithonian, could be gnored. Yet *Trigonia crassa* in Cutch, which he regarded as dentical with his *T. smeei*, was known by him to have been described s occurring in association with Trigonias of the exclusively retaceous sections Scabrae and Pseudo-quadratae. The suggestion hat this definite record of *T. smeei* in the Neocomian *T. schwarzi* Bed could be so lightly set aside is far from being in agreement ith the clear statement made by Hennig that *Trigonia smeei* ccurs by no means rarely ("findet sich gar nicht selten") in the *rigonia schwarzi* Bed. In fact Professor Hennig admitted that he imself found it near Ntandi to be prevalent in that Neocomian one.[3] The shells referred to are so strongly characterized that hey could not conceivably be confused with anything else; yet hen describing his *Trigonia smeei* Lange only mentioned the one pecimen, the evidence of which he afterwards tried to discount, nd no comment was made on Professor Hennig's experiences. rofessor Krenkel also had previously noted that Lange's *T. smeei*" (Müller's *T. beyschlagi*, regarded as identical by Lange) ccurred at one locality associated with Müller's *Trigonia bornhardti*, scribed by Lange to the *Trigonia schwarzi* Bed.

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[1] E. Lange, "Die Brachiopoden, Lamellibranchiaten und Anneliden der rigonia Schwarzi-Schicht, nebst vergleichender Übersicht der Trigonien der esamten Tendaguruschichten," *Archiv für Biontologie*, Band iii, Heft 4, 1914, p. 263, 268.

[2] E. Lange, "*Trigonia smeei* Sowerby und ihre horizontale Verbreitung," *entralbl. für Min.*, etc., 1917, p. 496.

[3] E. Hennig, "Beiträge zur Geologie und Stratigraphie Deutsch-Ostafrikas," *rchiv für Biontologie*, Band iii, Heft 3, 1914, pp. 15, 25, 26.

The only other *Trigonia* recorded by Lange from the "*Trigonia smeei*" zone, in the collections made by the Expedition, was his *T. dietrichi*.[1] This cannot be brought into any known Jurassic group of the genus, but bears no little resemblance to *Trigonia niongalensis* Lange, from the Neocomian *Trigonia schwarzi* zone, figured on the same plate of Lange's work. Moreover, a specimen of *T. dietrichi* ascribed to Locality 13, near Tendaguru, should be from the *T. schwarzi* zone, according to Professor Hennig's geological map issued with Band iii, Heft 3, of *Archiv für Biontologie*.[2] Lange recognized the discrepancy that this would involve, and he attempted to reduce the number of species which would accordingly have to be given an admitted range from Kimmeridge to Neocomian by suggesting a doubt: "This species belongs to the *Trigonia smeei* Bed, in consequence of which it is not certain that it really fits in with Locality 13."[3] But Professor Hennig has assured us that the work done in establishing with accuracy the succession and distribution of the beds was amply sufficient, and that the recording and numbering of specimens collected was so carefully carried out that no confusion could arise.[4] I will accept those statements, and conclude that *Trigonia dietrichi* occurs in the "*T. smeei*" zone, and also in the Neocomian *T. schwarzi* zone.

One more of these awkward records of a species occurring both in the alleged Kimmeridge "*T. smeei*" zone and in the *T. schwarzi* zone is provided in the material obtained by the Expedition. Lange did not attempt to explain this away by suggesting another error, but said frankly that in this species, *Gervillia dentata* Krauss, we have a form which is common to the Neocomian and Tithonian (= Kimmeridge) marine deposits of Tendaguru.[5] Dietrich, in referring to this, says: "What can a *Gervillia* tell us about age in the middle of a mass-occurrence of Trigonias; it is admitted that *Gervillias* of that kind occur everywhere with Trigonias!"[6] The answer to that comment is that *Gervillia dentata* (or its like) does not occur in Middle or Upper Kimmeridge beds, but it does occur in Lower Cretaceous strata in South Africa and probably also in Cutch (in association with *Trigonia smeei*), as well as in admittedly Neocomian beds in the Tendaguru district. Lange expressly stated that the specimens he was examining agreed completely with the descriptions given in previous publications. The occurrence of *Gervillia dentata* below the Upper Saurian Beds as well as above them seems to me to have considerable significance, in view of what

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[1] Op. cit., 1914, p. 233, pl. xx, fig. 7.

[2] See also the map giving the localities for the invertebrate fossils, *Archiv für Biontologie*, Band iii, Heft 4, 1914, p. 4.

[3] Op. cit., 1914, p. 265.

[4] E. Hennig, "Die Altersfragen der Tendaguru-Schichten im südlichen Deutsch-Ostafrika," *Centralbl. für Min.*, etc., 1927, pp. 66, 67.

[5] Op. cit., 1914, p. 205.

[6] W. O. Dietrich, "Das Alter der Trigonienschichten am Tendaguru," *Centralbl. für Min.*, etc., 1927, p. 62.

I have said above about some of the other bivalves found in the "*Trigonia smeei*" zone.

This brings us to consider briefly a few of the species previously recorded by G. Müller and by E. Krenkel.[1] Lange states that the specimens from the locality Matapua of Krenkel's publication belong to the "*Trigonia smeei*" zone ("Tithonian"), not to the Neocomian, as previously thought. In like manner the specimens described by G. Müller from the Nkundi Stream also belong to the "*T. smeei*" zone. The reasons given by Lange in each case are convincing. Thus we get his conclusion, already quoted, that *Seebachia bronni* (Krauss), *Eriphyla herzogi* (Krauss), *Trigonia ventricosa* (Krauss), and *Gervillia dentata* Krauss, all belonging to the Uitenhage Neocomian, actually occur in "Tithonian" beds (that is to say Kimmeridge, according to the ammonites of the "*Trigonia smeei*" zone), and extend in their range up to Neocomian. Dietrich, however, thinks that some of Müller's and Krenkel's determinations are so doubtful that Lange would have done better to ignore them. Thus he states[2]: "It would have been easy for Kitchin to have ascertained that: (1) *T. ventricosa* in Müller was founded on 2–3 doubtful and badly preserved shells from Nkundi Stream; (2) *Seebachia bronni* and *Eriphyla herzogi* in Krenkel, each represented by one poor specimen from Matapua (collection by natives!), are in fact strongly doubted, as regards their determination, by Lange himself." This is scarcely fair comment. Although Müller's specimens ascribed to *Trigonia ventricosa* were not well preserved, their significance as undoubtedly belonging to the *T. ventricosa* group, which is quite clear from the description and figure, is just the same as if they had been perfectly preserved. Such forms are certainly Neocomian and not Jurassic. Lange did not doubt the correct determination of the *Seebachia* because only a single or poorly preserved specimen had been found; he doubted it because he believed it to have come from a Tithonian horizon ("*T. smeei*" Bed) and not a Neocomian horizon (op. cit., p. 266). At the same time he admitted that Krenkel had stated that, although not well preserved, the specimen is an undoubted *S. bronni* (p. 274).[3] A similar doubt arose in Lange's mind in the case of Krenkel's *Eriphyla herzogi*, to which he also ascribed a Tithonian age; and he suggested that this shell and the *Seebachia* might be related to the closely similar forms which occur in the Oomia *Trigonia* beds in Cutch (supposed by him to be Tithonian), rather than to the Uitenhage forms (Neocomian) of South Africa. But the significance of the comparison as bearing on the age of the "*Trigonia smeei*" sandstones is the same in either case, since the species in Cutch occur really in Lower Cretaceous and not in Tithonian horizons. The bivalves we have been considering are not of generalized, equivocal type, and their cumulative effect as evidence for age is indisputable. From the foregoing examination we must therefore conclude that the sandstones between the Middle and Upper Saurian Beds are of Neocomian age, and that they are closely connected by their fauna with the Valanginian of the *Trigonia schwarzi* zone, above the Upper Saurian deposits, and with the Uitenhage Series in South Africa. The further conclusion must follow that any Jurassic ammonites found in the so-called *Trigonia smeei* zone are not in their original position.

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[1] J. Müller, "Versteinerungen des Juraund der Kreide," in W. Bornhardt's "Zur Oberflächengestaltung und Geologie Deutsch-Ostafrikas," *Deutsch-Ost-Afrika*, Band vii, Theil 2, pp. 514–71, Berlin, 1900. E. Krenkel, "Die untere Kreide von Deutsch-Ostafrika," *Beiträge zur Pal. und Geol. Oesterr.-Ungarns und des Orients*, Band xxiii, 1910, pp. 201–50.

[2] *Centralbl. für Min.*, etc., 1927, pp. 61, 62.

[3] E. Krenkel, op. cit., p. 236.

Some of these ammonites ascribed to the zone by Zwierzycki[1] have not been shown to come with certainty from that zone. Such are the specimens recorded as *Phylloceras silesiacum* Oppel (Localities 8 of the table given by Janensch and Hennig,[2] and the Mbemkuru slope near Kindope); *Haploceras elimatum* Opp. (Localities 8 and 19*b*); "*Craspedites*" *africanus* sp. nov (Loc. 8); *Perisphinctes bleicheri* de Lor., an incorrect determination, and the locality and horizon unknown; and *Perisphinctes latissimus* sp. nov., found as a loose pebble in the Tingutinguti Stream, which crosses both the "*Trigonia smeei*" zone and the *Nerinea* zone within a relatively short distance on the map. The horizon for Locality 8 (collection made by natives) is given by Janensch and Hennig as "Chiefly Smeei Bed ?"; that for Locality 19*b* as "Smeei Bed ?" Dietrich has published a revised list of the ammonites from the "*Trigonia smeei*" zone at two other localities.[3] These need not be discussed; undoubtedly here are Kimmeridge ammonites, and we must accept the statement that they were obtained in the "*Trigonia smeei*" zone. But the zone must be dated stratigraphically by its latest fossils, and the evidence for a Neocomian age is in my opinion overwhelming. There seems, indeed, to be no reason for regarding it as earlier than Valanginian.

Not only are these ammonites associated with a bivalve fauna that is unknown to occur at any Jurassic horizon in any other part of the world, but the character of the beds constituting the "*Trigonia smeei*" zone is such that there could be little expectation of finding indigenous ammonites in them. It may be asked whether the ammonites were obtained at different levels in the series or chiefly or wholly at a particular level; whether they were found as isolated specimens or segregated together; and whether they were embedded in the coarsely sandy or conglomeratic matrix of the zone, or whether each one occurred in a pebble or in a nodule-matrix different from that of the surrounding rock. In Professor Janensch's description of the zone [1] there is mention of a band, less than a foot in thickness, situated about 25 feet above the base, in which "*Trigonia smeei*" occurs particularly numerously. This band of medium to coarse-grained sandstone contains large, much rolled quartzes and felspars and occasional rolled pebbles of sandstone. The bed is rich in fossils, particularly thick-shelled molluscs, and also corals. When traced towards the south-east the band becomes rich in oolite-grains. The description suggests the likelihood that derived fossiliferous pebbles or sandy nodules may be present here. Lange mentioned,[2] moreover, that the Trigonias, which are certainly indigenous, show signs of rolling and wear which occurred possibly during life and at the latest shortly after death. He stated that this circumstance and the mineralogical changes due to fossilization were unfavourable for the preservation of the sculpture. The state of some of the ammonites suggests that they were not exposed to these destructive processes, and their relatively good preservation would be explained if they occurred embedded in derived pebbles or nodules. Is it not possible that the ammonites, collected without a suspicion that they would prove to belong to Jurassic species, were sent to Germany, were then cleaned and freed from their matrix, and only after this necessary preparation examined in detail and determined as Jurassic? Important clues to their secondary mode of occurrence might thus, by these accidental circumstances, be lost.

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[1] J. Zwierzycki, "Die Cephalopodenfauna der Tendaguru-Schichten in Deutsch-Ostafrika," *Archiv für Biontologie*, Band iii, Heft 4, 1914, p. 7. (Issued as a separate in 1913.)

[2] W. Janensch and E. Hennig, "Tabellarische Übersicht der Fundorte wirbelloser Fossilien im Arbeitsgebiete der Tendaguru-Expedition," *Archiv für Biontologie*, Band iii, Heft 4, 1914, p. 5.

[3] *Centralbl. für Min.*, etc., 1927, p. 62. See also another list given by Dietrich, "Über eine dem mittleren Sauriermergel am Tendaguru äquivalente, rein marine Kimmeridgebildung in Mahokondo, Deutsch-Ostafrika," *Palaeontographica*, Suppl. vii, Reihe ii, Teil 1, Lief. 1, 1925, p. 21.

As for the remaining invertebrates of the "*Trigonia smeei*" zone so far investigated, these are considered to be a Jurassic assemblage by Dr. Dietrich. Apart from the few ammonites, I can see nothing in the fossils themselves to support this. If the corals that are stated to be actually growing on the valves of "*Trigonia smeei*" have been determined as Jurassic forms, it will merely be necessary to abandon the view that they are really Jurassic, and to regard them now as part of a Lower Cretaceous fauna. These corals [3] give no indication of age that can outweigh the evidence for Neocomian that has been discussed above. The same criticism must apply to Hennig's determination of the invertebrate forms found in the marine bed at the base of the "*Trigonia smeei*" zone, classified as the top member of the Middle Saurian Beds and forming a passage-bed between those deposits, of mixed facies, and the purely marine sandstones overlying them. The work of determining these invertebrate fossils, as in the case of those belonging to the "*Trigonia smeei*" zone, was carried out with the natural prejudice resulting from a belief that the ammonites found in the "*Trigonia smeei*" sandstones are the most certain index to the geological age of both those deposits. The question then arises, can the Middle Saurian Beds be regarded as Jurassic?

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[1] *Archiv für Biontologie*, Band iii, Heft 3, 1914, p. 229.

[2] *Centralbl. für Min.*, etc., 1917, p. 494.

[3] W. O. Dietrich, "Steincorallen des Malms und der Unterkreide im südlichen Deutsch-Ostafrika," *Palaeontographica*, Suppl. vii, Reihe ii, Teil 1, Lief. 2, 1926, p. 41.

IV. THE AGE-RELATIONS OF THE UPPER AND MIDDLE SAURIAN BEDS.

We have seen that the Upper Saurian Beds are so situated within a Neocomian marine series, no part of which shows evidence of an age earlier than Valanginian, that their position in the Lower Cretaceous time-scale is determined within narrow limits. The Middle Saurian Beds show clearly by their palaeontological characters, and by their intimate stratigraphical connection with the "*Trigonia smeei*" sandstones, that they must also be regarded as part of the same Lower Cretaceous series.

Professor Hennig has made it evident that the top bed of the Middle Saurian Beds is in stratal continuity both with the deinosaur-marls beneath it and with the marine sandstones above. He mentions as an exceptional occurrence a minor intra-formational discontinuity here at Locality 15 (Mtapaia), but states that if the cause of this amounted to so much as an actual emergence and slight erosion, it must have been of short duration.[1] This top bed, which shows the coming in of purely marine conditions at the close of the period of the saurian-marls containing numerous specimens of *Cyrena*, yields a fauna which joins it most intimately with the "*Trigonia smeei*" zone. But the matrix of fine-grained sandy marl is so similar to that of the upper part of the true saurian-bearing deposits beneath that the conditions of sedimentation seem hardly to have altered with the change to the more purely marine facies. This top bed has yielded, among other bivalves, *Protocardia schencki* G. Müller, which occurs above in the "*Trigonia smeei*" zone, and also, according to Lange, in the Neocomian *Trigonia schwarzi* zone. Another species found here is *Trigonia dietrichi* Lange, which, as we have seen, has a precisely similar range up to the *T. schwarzi* zone. Of equal interest and significance is an elongated, well ornamented *Modiola*,[2] which Hennig identified with the Jurassic *M. perplicata* Etallon. If he had thought that his material could be of Neocomian age, and if he had not been fettered by the conviction that a Kimmeridge age had been proved, he would doubtless have recognized in this species the Neocomian *Modiola baini* Sharpe, of the Uitenhage Marine Beds in South Africa,[1] with which it appears to be identical. This form occurs also in the "*Trigonia smeei*" zone, and as we shall see, has special interest from the fact that it has also been found in the *Nerinea* zone (below the Middle Saurian Beds), where it is said to occur most prevalently.[2] I have already mentioned that Professor Hennig believed the specimens of *Cyrena* occurring abundantly in the Middle and Upper Saurian deposits to be specifically identical.

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[1] E. Hennig, "Die Invertebraten-Fauna der Saurierschichten am Tendaguru," *Archiv für Biontologie*, Band iii, Heft 4, 1914, p. 164.

[2] E. Hennig, op. cit., p. 176, pl. xiv, fig. 4.

The deinosaurs of the Middle Saurian Beds provide, however, the most striking proof of the close relationship in time between these deposits and the Upper Saurian Beds. Dr. G. G. Simpson wrote: "It is clear that the faunas of the two zones are practically identical, all the differences being possibly due to the fortunes of collecting."[3] He set out in parallel columns the names of the described species of deinosaurs found in the two horizons, and the intimately related character of the faunas is evident from the occurrence in both of *Brachiosaurus brancai* Janensch, *B. fraasi* Janensch, *Kentrurosaurus aethiopicus* Hennig, *Elaphrosaurus bambergi* Janensch, *Allosaurus* ? *tendagurensis* Janensch, *Ceratosaurus* ? *roechlingi* Janensch, *Megalosaurus* ? *ingens* Janensch, and *Labrosaurus* ? *stechowi* Janensch, as well as representatives of the genus *Dicraeosaurus*. There is thus identity in representatives of diverse groups of deinosaurs, the sauropods, the theropods, and the stegosaurs. It is quite inconceivable that even one of these species, or indeed any species of marine mollusc, should have had a range of existence from Lower or Middle Kimmeridge up to Valanginian. It is clear that both the Middle and Upper Deinosaur Beds belong to a narrowly limited subdivision of Lower Cretaceous time, and in my opinion there is no evidence to suggest that they are older than Valanginian.

V. THE AGE OF THE *NERINEA* ZONE.

The question of the age of these marine beds underlying the Middle Saurian Beds may be discussed in a few words. The *Nerinea* zone seems to have been little investigated, for we find only a brief account of its lithological and palaeontological characters in the Tendaguru monographs. Mr. John Pringle, of the Geological Survey of Great Britain, who is very experienced in weighing evidence for correlations in the Mesozoic rocks, recently undertook, at my request, to make an independent study of these monographs, in order to be able to criticize my own conclusions with a mind free from preconceptions. He soon formed the definite opinion that the base of the Lower Cretaceous series at Tendaguru should be drawn below the Middle Saurian Beds, and this result was reached by him before I had arrived at the same conclusion. So far we find ourselves in complete agreement. The next question is, should some upper part of the *Nerinea* zone, or even the whole of that zone, also be linked up with the Lower Cretaceous series above it? Unfortunately, the information available is so meagre that only a suggestion can be made. The cephalopods described by Zwierzycki from these beds include *Nautilus*, *Haploceras*, and *Perisphinctes*. We do not know how they occurred in the series, except that a fragment named *Perisphinctes* cf. *achilles* d'Orb. was found at the base of the Middle Saurian Beds. Two other species of *Perisphinctes*, each represented by one specimen, were ascribed to Localities 8 and 19*b*. It may be recalled that the horizon for Loc. 8 (collection made by natives) is given by Janensch and Hennig[1] as "Chiefly Smeei Bed?"; and that for Locality 19*b* as "Smeei Bed?" The information given is thus in part too scanty and in part unsatisfactory. Dr. Dietrich has published a revised list of the ammonites ascribed to this zone (based partly upon Reck's observations), and according to him and to Dr. Spath the cephalopods of the zone are of Kimmeridge age.[2]

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[1] F. L. Kitchin, "The Invertebrate Fauna and Palaeontological Relations of the Uitenhage Series," *Ann. South African Museum*, vol. vii, part ii, 1908, p. 85, pl. ii, fig. 12.

[2] E. Hennig, op. cit., pp. 178, 179.

[3] G. G. Simpson, "The Age of the Morrison Formation," *Amer. Journ. Sci.*, Ser. v, vol. xii, 1926, p. 210.

It would be of great interest to know how these ammonites were found distributed in the series, and whether they were encased in isolated nodules or were embedded directly in the sandy matrix of the zone itself. The size of some of them seems, perhaps, to suggest that they are unlikely to have been obtained from derived nodules, and it therefore becomes important to know whether all the specimens were found high up in the zone, or whether some of them occurred at lower levels. At the same time it must be noted that Professor Janensch's description of the beds constituting this zone recalls strikingly the characters of the "*Trigonia smeei*" zone. There is mention of a bed situated about 20 feet above the base, consisting of fine-grained, grey calcareous sandstone with numerous clayey or clayey-sandy rounded inclusions, with the suggestion that these may be rolled pebbles. Is it not possible that such pebbles or nodules might have yielded Jurassic ammonites? If specimens of Kimmeridge age could be derived into the "*Trigonia smeei*" zone without this fact becoming suspected until too late for checking or confirming observations to be made, could this not also happen in the case of those found below the Middle Saurian Beds?

From the account given by Professor Hennig of the basal bed of the Middle Saurian deposits, it would appear that there is no evidence of a break or discontinuity of deposition there. He states indeed that at one locality showing the basal bed (with skeleton "*p*") there is evidence provided by the fauna to show continuity with the *Nerinea* zone below.[1] From the scanty records of the marine invertebrates found in the *Nerinea* zone, it may be gathered that a few of the fossils actually range from that zone up into the "*Trigonia smeei*" zone. Such are: the "*Modiola perplicata*" of Hennig,"[2] which I consider to be the Neocomian *Modiola baini* Sharpe; *Nerinella credneri* (G. Müller)[3]; and "*Trigonia smeei*" itself, as noted by Professor Hennig.[4] This species, it will be remembered, ranges right up into the Neocomian *Trigonia schwarzi* zone. Another species recorded from the *Nerinea* zone is *Mytilus uitenhagensis* Kitchin, a well characterized shell with sharp keel and flat antero-ventral area, which occurs associated with undoubted Neocomian forms in the Uitenhage Beds. The presence of this shell in the *Nerinea* zone was noted by Professor Hennig in his account of the invertebrate fauna of the Saurian Beds.[5] These records do not agree well with an association with ammonites of Kimmeridge or earlier stage; and it may be suggested that here also, just as in the case of the "*Trigonia smeei*" zone, we are dealing with a part of the rapidly accumulated Lower Cretaceous deposits of this district, and that the denudation of Jurassic strata in the vicinity provided the ammonites which, encased in their matrix (perhaps in the form of nodules), became swept into these sandy beds. There is no evidence, however, as yet, to show that the whole of the *Nerinea* zone is of one age, except that the description of its lithological characters suggests that all the beds within the zone belong to one series. To me it is quite inconceivable that Trigonias of the *T. smeei* group could have a range from the *Nerinea* zone up to the *Trigonia schwarzi* zone if the whole *Nerinea* zone is of Kimmeridge or earlier age. They might perhaps make their first appearance during Infra-Valanginian time, but it cannot be admitted that such forms could have had a long existence. Lange, in fact, assumed his *Trigonia smeei* to be a relatively short-lived species[6]; but how this is to be reconciled with the supposedly enormous range given to it by the German investigators themselves passes understanding.

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[1] *Archiv für Biontologie*, Band iii, Heft 4, 1914, p. 5.

[2] L. F. Spath, *Mon. Geol. Dep. Hunterian Museum, Glasgow Univ.*, i, 1925, pp. 159, 160. W. O. Dietrich, *Palaeontographica*, Suppl. vii, Reihe ii, Teil 1, Lief. 1, 1925, p. 20 ("Lower Kimmeridge, Middle Kimmeridge").

The exact age of the whole *Nerinea* zone is not yet proved beyond doubt; but there are facts which indicate that at least some upper part of it is of Lower Cretaceous age (Valanginian or, at the oldest, Infra-Valanginian), and that even the whole zone may be of that age.

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[1] *Archiv für Biontologie*, Band iii, Heft 4, 1914, p. 165.

[2] Op. cit., pp. 178, 179.

[3] W. O. Dietrich, "Die Gastropoden der Tendaguruschichten," etc., *Archiv für Biontologie*, Band iii, Heft 4, 1914, p. 144.

[4] "Geologisch-stratigraphische Beobachtungen im Küstengebiete des südlichen Deutsch-Ostafrika," *Archiv für Biontologie*, Band iii, Heft 3, 1914, p. 15 (separate issued in 1913).

[5] *Archiv für Biontologie*, Band iii, Heft 4, 1914, p. 160, footnote.

[6] *Archiv für Biontologie*, Band iii, Heft 4, 1914, p. 282.

VI. CONCLUDING REMARKS.

We have now seen that, apart from the Jurassic ammonites found in the sandy marine deposits below and above the Middle Saurian Beds, the palaeontological data made available by the descriptions so far published show the close connexion between the three sets of marine beds, the so-called *Nerinea* zone, the so-called *Trigonia smeei* zone, and the *Trigonia schwarzi* zone, admittedly of Neocomian age. The "*Trigonia smeei*" of E. Lange belongs to a group of degenerate Costate Trigonias known elsewhere with certainty only in India, where representatives of the group are associated with Neocomian species. The characters of this group are of a special type which, by all analogies, points to a short geological life for the forms comprised within it. It is therefore a most significant fact that shells of the group range from the *Nerinea* zone up to the *Trigonia schwarzi* zone, where they are found in considerable numbers associated with a fauna which, it is agreed, is of Neocomian age. Other molluscs of Neocomian type connect the *Nerinea* zone with the "*Trigonia smeei*" zone, and this latter zone with the *Trigonia schwarzi* zone. The two series of beds of different facies intercalated in this succession of rapidly accumulated marine sandstones, namely, the Middle and Upper Saurian Beds, have yielded a fauna of remarkable deinosaurs, a number of which occur in common at the two levels. In fact, the faunas of these two deinosaur-deposits may be said to be identical. The only possible conclusion seems to be that the Jurassic ammonites found in the "*Trigonia smeei*" sandstones are not in their original position, but were derived into those beds, the true age of which must be determined by their latest fossils. The Middle and Upper Saurian Beds are therefore of Neocomian age. We may even doubt whether the upper part of the underlying *Nerinea* zone is as old as Infra-Valanginian. There is insufficient evidence on which to base an opinion; but some of the bivalves point at least to a lower Cretaceous and not a Jurassic age. Both the palaeontological and lithological signs indicate the rapid mode of deposition of the marine sandstones, so that a short time-range for the whole series seems probable.

We have therefore arrived at an interpretation that fits in more closely with the idea of the German investigators, that there is a continuous set of deposits showing no marked break from the *Nerinea* zone up to the *Trigonia schwarzi* zone. In the present discussion it is unnecessary to consider the overlying Makonde Series (Aptian) or its relation to the Neocomian beds below; but the supposed continuity and completeness of deposition was thought by the authors of the German monographs to extend from beds of "Oxford" age up into the Aptian. Such an interpretation must lay much too severe a strain even on a credulous mind. Even though we must conclude that most of the Tendaguru Series, if not also its lowest part, is of Lower Cretaceous age, it is improbable that there is complete zonal representation in the marine beds actually present; while the deinosaur-deposits more evidently interrupt the record and destroy the continuity of a marine series that would otherwise have more nearly approached completeness.

This incompleteness in the marine succession doubtless suffices to explain the difficulty of correlating with precision the Neocomian *Trigonia* beds of South Africa, Tanganyika Territory and Cutch. There is evidence enough in their bivalve-faunas that they were laid down on the margin of a connected sea, and that there was free intercourse for some of their typical species, or closely related members of the species-groups which so well characterize these beds. The invertebrate fauna of the marine beds in the Tendaguru Series shows clearly a relationship to that of the Oomia *Trigonia* beds on the one hand and that of the marine part of the Uitenhage Series on the other. An exhaustive discussion of these relationships would take us somewhat beyond the scope of this paper, but a few words may be added.

We have seen that some of the species of the Neocomian Uitenhage Beds, and other forms very closely related to species found in that formation, occur at Tendaguru in the *Nerinea* zone, in the "*Trigonia smeei*" zone, and in the *Trigonia schwarzi* zone. In addition to the species mentioned in the foregoing pages, the *Trigonia schwarzi* zone has yielded the characteristic Uitenhage bivalves *Trigonia conocardiiformis* (Krauss), *Cucullaea kraussi* Tate, and *Eriphyla pinchiniana* Tate, and perhaps also *Perna atherstoni* Sharpe and an *Exogyra* related to *E. imbricata* Krauss. It is therefore remarkable that Trigonias of the *T. smeei* group are unknown as yet in South Africa. This may possibly be due to the fact that those Trigonias, where known, occur in sediments of coarse gritty character evidently laid down under the influence of strong currents. They may have been strictly limited to a habitat of that kind; but there may have been other factors accounting for their absence from the Sundays River Beds.

We are still imperfectly informed regarding the relationship of the marine beds of the Uitenhage Series to the associated strata of Wealden type in the same area. As at Tendaguru, there were conditions fluctuating between those of purely marine and purely freshwater character; but these are less clearly and less constantly shown in any continuous section than at Tendaguru. The variability of development and the fluctuations of facies in the Uitenhage Beds are described in the general account given by Rogers and Du Toit,[1] who give references to the more special literature. It may perhaps be of significance that *Mytilus uitenhagensis* Kitchin and *Modiola baini* Sharpe, which are found below the Middle Saurian Beds at Tendaguru, occur in the lower part of the Uitenhage Marine Beds as developed at the localities where these forms have been found in South Africa. Lange expressed the opinion that the Uitenhage Marine Beds should be correlated with the Upper Saurian Beds of Tendaguru[1]; but if we abandon the idea that the "*Trigonia smeei*" zone there is of Jurassic age, the question of an exact correlation becomes less easy. It may suffice here to recognize that there are faunal links with the Uitenhage Beds in all the marine beds of the Tendaguru Series and to refrain from any detailed discussion, which at present must consist largely of surmise. It is of interest to recall that remains of deinosaurs have been shown to be present in some of the freshwater developments of the Uitenhage Series.[2]

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[1] A. W. Rogers and A. L. du Toit, *An Introduction to the Geology of Cape Colony*, 2nd ed., 1909, pp. 289–326.

An exact correlation between the Tendaguru Series and the Lower Cretaceous *Trigonia* beds of Cutch is equally difficult to establish. It might be supposed that the fauna containing the true *Trigonia smeei*, found in Eastern Cutch (Wagur), lived at a time when the Middle Saurian Beds of Tendaguru were being deposited; and that the fauna containing *Trigonia crassa*, found in Western Cutch, corresponds in time with the Upper Saurian Beds. No satisfactory discussion can be conducted until we have a full and rational account of the Trigonias of the *T. smeei* group found in the *Nerinea* Beds and those of the *Trigonia schwarzi* zone. Only those found in the intermediate marine strata between the two deinosaur-deposits have so far been described and illustrated; and the account of these already given leaves much to be desired. A general relationship to these Neocomian beds in Cutch is, however, well established.

The fact that some of the special monographs resulting from the work of the German Tendaguru Expedition show many signs of confused thinking and too hasty preparation is much to be regretted. The work done by Professors Janensch and Hennig in the face of many difficulties, both the geological mapping of a most difficult country and the skilled excavation and removal of the remains of deinosaurs on so large a scale, can only be described as magnificent.

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[1] *Archiv für Biontologie*, Band iii, Heft 4, 1914, p. 287.

[2] R. Broom, "On the Occurrence of an Opisthocoelian Dinosaur (*Algoasaurus bauri*) in the Cretaceous Beds of South Africa," GEOL. MAG., 1904, p. 445. E. H. L. Schwarz, "Note on South African Cretaceous Dinosaurs," GEOL. MAG., 1913, p. 263.

Metasomatism in the Whin Sill of the North of England.
Part II: Hydrothermal Alteration by Juvenile Solutions.

By L. R. Wager, B.A., Pembroke College, Cambridge.

The Early Joints.

IN Teesdale and Weardale, at all exposures that have been examined, the Whin Sill is cut by a system of approximately vertical, weeping, joint planes. These are distinct in general character rom, and are on a larger scale than, the columnar jointing which is onspicuous in all vertical scars of Whin Sill. The pattern of the arger scale jointing on a horizontal surface varies with the depth within the sill; Fig. 1 shows diagrammatically the appearance at a depth of about 10 feet below the top of the sill; the inset Fig. 2, of the upper surface of the sill, shows how the joints have a more rregular course in the more rapidly cooled part of the dolerite. The joints do not usually pass from the dolerite into the adjacent ediment and Fig. 2 also shows a thin layer of baked sediment, attached to the outer surface of the sill, which the joint does not penetrate. The large scale jointing is often displaced by the small cale columnar jointing in a way that proves the large scale jointing o be the earlier. For the purposes of this paper, the early, large scale, oints will be referred to simply as the *early joints*. The walls of he early joints, for a distance of an inch or so, have been altered by hydrothermal solutions, to a rock which, although varying in composition with the distance from the joint, consists essentially of chlorite, quartz, and carbonate. The joint walls are usually about a quarter of an inch apart, and the space between them is filled with calcite and quartz. The calcite is present in greater abundance than the quartz which occurs in well shaped crystals of vein-quartz habit.

A system of joints showing a somewhat similar pattern to that of the early joints of the Whin Sill has been described and figured by Sosman [1916, pp. 217–19] and Wherry [1912, pp. 169–72]. Sosman has suggested that they were formed at a time when the dolerite could support only a very small tensional stress, and he has compared them to cracks produced by contraction in such a substance as drying mud, consisting of both liquid and solid material. Wherry states that the joints which he has examined, are filled with typical dolerite, only to be distinguished by a coarser grain from the material of the walls of the joint and that they have no great vertical extension, becoming ill-defined, and finally lost, after penetrating a few centimetres into the sill. The early joints of the Whin Sill were formed at a relatively later stage than the joints described by Sosman and Wherry and the mesostasis must have finished crystallizing by he time they were formed. The irregularity of the pattern of he early joints of the Whin Sill, suggests, however, that in this case also, they were formed when the temperature was high and the dolerite could support only small tensional stress. The hydrothermal alteration of the walls of the joints shows that they were formed at a relatively early stage, either before, or contemporaneously with,

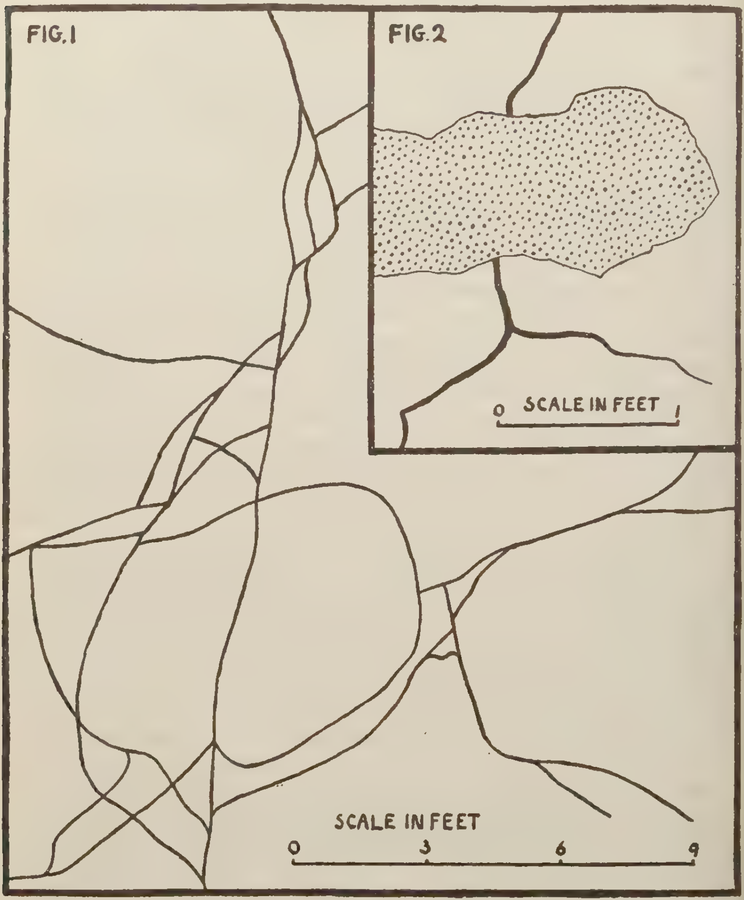

Fig. 1.—Pattern of the early joint system, on a horizontal surface about 20 feet below the top of the Whin Sill in the bed of the River Tees, 200 yards upstream from Winch Bridge.

Fig. 2.—Form of the early joint system at the upper surface of the Whin Sill, Ord and Maddison's Quarry, Middleton in Teesdale. The stippled area represents a thin layer of baked sediment which the early joint does not penetrate.

the existence of active hydrothermal solutions. The present paper is principally concerned with the hydrothermal alteration of the dolerite along the early formed joints.

PETROGRAPHY OF THE HYDROTHERMALLY ALTERED DOLERITE ADJACENT TO THE EARLY JOINTS.

Localities for the Material Examined.

Alteration of the walls of the early joints is conspicuous because of differential weathering and erosion in the exposures of the Whin Sill in the bed of the Tees near Winch Bridge, Holwick (Locality 1). Good material may be collected in Ord and Maddison's Quarry at Middleton in Teesdale (Locality 2), and in the road metal quarry at Cowshill in Weardale (Locality 3). Although the following description is based on material collected only at the above localities, similar alteration has been found along early joints at many other exposures in Teesdale.

The Normal Transition to the Hydrothermally altered Dolerite.

There is a variation, within certain limits, in the mineralogical composition of the altered material immediately adjacent to the early joints. The essential constituents are chlorite, quartz, anatase, and apatite, but carbonates and alkali felspar may be present in addition. In some cases an altered rock, which, a centimetre or so from the joint, includes carbonates and alkali felspar, becomes a chlorite-quartz-rock, free from carbonates and with only a trace of felspar, immediately adjacent to the joint. A rock consisting essentially of chlorite and quartz is therefore to be regarded as the extreme product of the hydrothermal metasomatism. Specimens collected about 40 feet below the upper surface of the sill in Ord and Maddison's Quarry (Locality 2) will be described first, since they are typical of the transition from unaltered dolerite to the extreme type of alteration product.

Fig. 3, which is constructed in the same way as the diagram showing the transition from unaltered Whin Sill to white whin which has already been described (see Part I, page 106), summarizes the more complicated transition resulting from the hydrothermal metasomatism. The hypersthene at 5 cm. from the joint shows the first signs of alteration and at 4·5 cm. it is completely replaced by a mineral which is considered to belong to the ill-defined mineral species, *bowlingite.*

Usually the pseudomorphs are an aggregate of fibrous crystals, but they may rarely be found to consist of a single large crystal having the following properties :—

One perfect cleavage and one good cleavage at right angles.

The optic plane parallel to the good cleavage ; the acute bisectrix, X, perpendicular to the perfect cleavage, the elongation is therefore positive and the sign negative. Optic angle variable, usually between 15° and 30°.

Refractive indices, determined by the immersion method : μ_g about equal to $\mu_m = 1{\cdot}60\ (\pm\ {\cdot}01)$, $\mu_p = 1{\cdot}56\ (\pm\ {\cdot}01)$. Birefringence, by comparison with quartz : ·036–·037.

Absorption : $Z = Y > X$: Z and Y dark yellow green, X straw yellow

The rhombic pyroxene, from which the bowlingite was formed, is negative with $2V$ about 65°. This suggests that its composition is approximately 35 per cent $FeSiO_3$ and 65 per cent $MgSiO_3$ [Cf. Winchell, 1927, p. 177]. The orientation of the pseudomorph is such that Y of the hypersthene becomes X of the pseudomorph. Some variation was found in optical properties. The absorption was often feeble, Z and Y being pale green,

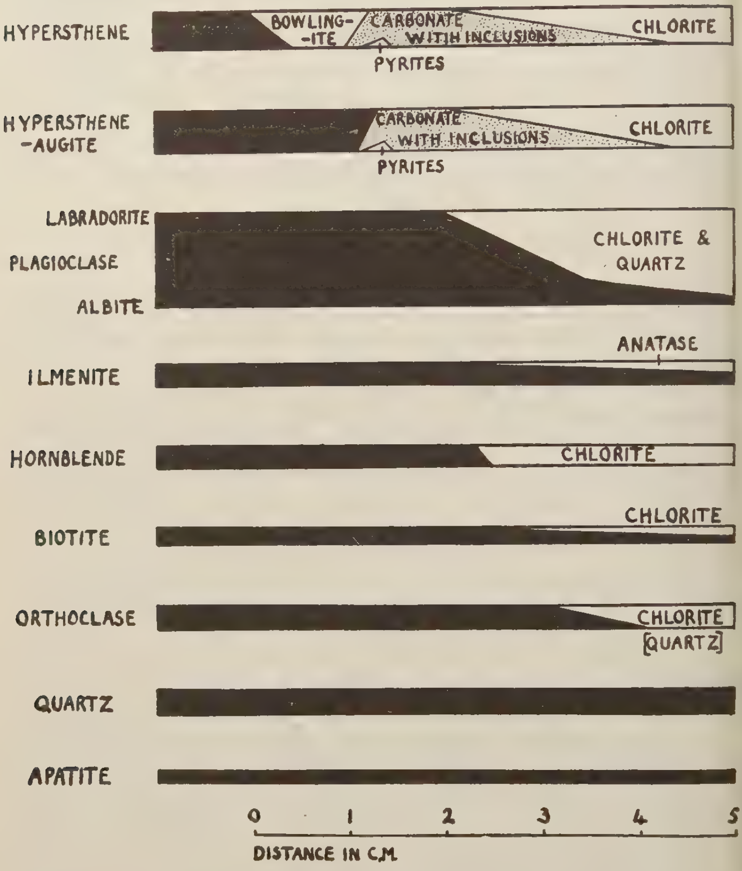

Fig. 3.—Diagram of the transition between the unaltered dolerite and the extreme type of hydrothermal alteration product. The black areas represent unaltered minerals. The diagram is limited on the right by the joint.

and the double refraction in rare cases was as low as ·025. One section with double refraction of ·026 gave $2V = 65°$.

It was found impracticable to make a separation of sufficient of the pseudomorph after hypersthene for analysis but certain conclusions as to its composition may legitimately be made. It is probable that alumina is not present to any significant extent, since the solutions, as will be shown later, contained very little aluminous material in solution at a distance of 3–5 cm. from the joint (see diagram 3). The presence of both ferrous and ferric iron is suggested by the intense colour. Since the formation of the pseudomorph after hypersthene takes place in advance of all the other changes, the amount of material introduced or removed during its formation is probably small, and its composition therefore probably approaches that of the original hypersthene.

Similar pseudomorphs after hypersthene have been described by Calkins [1902, p. 124] and Kišpatić [1912, p. 275], but the optical properties are not recorded in detail and no analysis is given. An iddingsite-like mineral, probably after rhombic pyroxene, has been noted by Falconer in the quartz-dolerites of the Bathgate and Linlithgow Hills [1906, p. 143] and Sir J. S. Flett [1910, p. 305] has observed, in some of the Scottish quartz-dolerites, a strongly pleochroic " biotite " after hypersthene, which may possibly be the same mineral. Incipient to complete alteration of the rhombic pyroxene in the Whin Sill is of widespread occurrence and is mentioned by Teall [1884, p. 652] and by Holmes and Harwood [1928, pp. 503, 511, and 518] although, in neither paper, are the optical properties given in detail. The mineral here described replacing hypersthene bears an obvious relation to iddingsite, which has recently been redefined, both in optical properties and chemical composition, by Ross and Shannon [1925]. Although the minerals, which they have classified as iddingsite, show a considerable range in properties, for instance the intermediate refractive index varies from 1·655–1·755, it would seem undesirable to use the name iddingsite for the pseudomorph under discussion and thus still further increase the range in properties of minerals referred to that species. Moreover, the iddingsite of Ross and Shannon was always a replacement of olivine. Lacroix [1893, pp. 442–6] has used the early name bowlingite for certain minerals, which, although resembling iddingsite as defined by Lawson [1893, pp. 31–6], were considered to differ too much from Lawson's iddingsite to justify the extension of the term to include them. If this was the case when Lacroix wrote in 1893, it is more applicable still since Ross and Shannon have redefined iddingsite in greater detail. On the other hand the mineral species named bowlingite by Hannay [1877, pp. 154–7] was never accurately defined by him. Lacroix used the name for minerals which, like iddingsite, were after olivine, but which were greenish or yellowish in colour and had a birefringence greater than ·025. The sign was negative and $2V$ was 0 to small. So far as it goes this description agrees with the mineral ascribed to bowlingite from the Whin Sill. Eckerman [1925, p. 276] has recently described a mineral from the Gevle basalt which he has called iddingsite. Its maximum refractive index of 1·63 is far below that of any iddingsite described by Ross and Shannon. The iddingsite from the Gevle basalt would seem to be transitional between the pseudomorph after hypersthene from the Whin Sill and the iddingsite of Ross and Shannon. Winchell, in his textbook of Optical Mineralogy [1927, pp. 382–3], has ascribed to bowlingite properties which closely agree with the material from the Whin Sill and he there states, that he considers bowlingite to be a variety of iddingsite. It seems possible that the iddingsite of Ross and Shannon is one end of a series of solid solutions of which the variable bowlingite minerals may be considered members.

In the transition between the altered and unaltered dolerite, the bowlingite is found to have a very short range of stability and, before any of the other minerals of the rock are appreciably attacked, the bowlingite is replaced by carbonates with a subsidiary amount of chlorite. The hypersthene-augite is next decomposed, and this s replaced, like the bowlingite, by carbonate with subsidiary chlorite. Within the carbonate formed from both the bowlingite and the hypersthene-augite, pyrites develops sporadically. The next change observed is in the plagioclase, which is gradually replaced by chlorite, and simultaneously the amount of chlorite in the former pyroxenes areas begins to increase. The more basic part of the plagioclase is decomposed first; the albitic margins and the orthoclase of the mesostasis, begin to decompose to chlorite, more or less simultaneously, at an appreciably greater distance from the limit of alteration, and some of the albite remains undecomposed in the most altered rocks. Soon after the beginning of the replacement

TABLE I.

	A.	B.	C.	D.	E.
SiO_2 .	36·98	50·80	35·1	— 15·7	24·95
Al_2O_3 .	15·02	14·24	14·2	·0	19·48
Fe_2O_3 .	2·34	3·84	2·2	— 1·6	3·33
FeO . .	18·33	8·90	17·4	+ 8·5	26·04
MgO .	9·78	5·12	9·5	+ 4·4	13·23
CaO . .	2·25	8·44	2·1	— 6·3	2·06
Na_2O .	·55	2·72	·5	— 2·2	
K_2O .	·18	1·32	·2	— 1·1	
H_2O + .	7·75	1·67	7·4	+ 8·2	10·91
H_2O — .	2·60		2·5		
CO_2 . .	·38	·21	·4	+ ·2	
TiO_2 .	3·53	2·20	3·4	— 1·2	
P_2O_5 .	·27	·21	·3	+ ·1	
S . .	Trace		Trace		
Co,Ni .	nt. fd.		nt. fd.		
MnO .	Trace	·23	Trace		
Zn, Cu. .	nt. fd.				
	99·96	99·90	95·2		100·00
S.G. . .	2·84	2·92			

A. Chloritic alteration product of the Whin Sill (the extreme type of hydrothermal alteration product within ·5 cm. of the joint) Ord and Maddison's Quarry, Middleton in Teesdale. Anal. W. H. Herdsman.

B. Average of three analysis of the Whin Sill (see previous paper, GEOL. MAG., 1929, p. 101).

C. Weights present in that amount of chloritic alteration product (Analysis A) which was formed from 100 grams of average Whin Sill (Analysis B) assuming neither gain nor loss of Al_2O_3.

D. Percentage gains and losses during metasomatism (values in column B subtracted from those of Column C).

E. Calculated percentage composition of the chlorite (diabantite) in the rock of analysis A.

of the plagioclase the ilmenite, hornblende and biotite begin to decompose. The formation of chlorite from the hornblende is an abrupt change while the replacement of ilmenite by anatase, and of biotite by chlorite, is a gradual process, usually only half complete in the most altered rock. The original quartz of the dolerite remains unchanged and throughout the slices at certain points there is an addition of new quartz in optical continuity with the original quartz. The added quartz is distinguished by abundant inclusion of chlorite.

patite, as in the alteration to white whin, occurs unchanged in he most altered rock.

The *chlorite*, which forms the bulk of the final rock, is of two slightly different kinds. One type occurs in large homogeneous crystals replacing the carbonate after pyroxenes and the progress of the replacement may be traced in detail. The first stage is marked by the stray flakes of chlorite, which were present in the carbonate from the time of its formation, increasing in numbers and becoming orientated approximately parallel to each other. At a later stage only corroded relics of carbonate occur poikilitically within large chlorite crystals, and finally the carbonate is completely replaced by a single, fairly homogeneous, crystal of chlorite. In the marginal part of these chlorites after carbonates, or just outside them, aggregates of anatase are usually to be seen which have been ejected from the carbonate areas during replacement by chlorite. It was possible to determine in some detail the properties of the larger chlorite crystals replacing carbonates. They have a perfect cleavage, which appears to be perpendicular to the acute bisectrix, and a poor cleavage parallel to the optic plane. The intermediate refractive index lies between 1·60 and 1·61 and the birefringence is ·012–·013. Absorption is $Z >$ or $= Y > X$ and X is light green and Z and Y are a little darker green. The sign is negative, and since X is perpendicular to the good cleavage the elongation is positive. $2V$ is variable even in a single section, but usually lies between 45° and 60°.

Table II.

Calculated mineralogical composition of the chloritic alteration product of e Whin Sill (analysis A, Table I).

Quartz				15·5
Chlorite	Amesite type	$2H_2O.2FeO(Al,Fe)_2O_3.SiO_2$	25·4	70·2
		$2H_2O.2MgO(Al, Fe)_2O_3{\cdot}SO_2$	19·2	
		$2H_2O.2CaO(Al, Fe)_2O_3.SiO_2$	2·2	
	Serpentine type.	$2H_2O.3FeO.2SiO_2$	13·2	
		$2H_2O.3MgO.2SiO_2$	9·0	
		$2H_2O.3CaO.2SiO_2$	1·2	
Albite				4·7
Ilmenite				3·3
Anatase				1·8
Biotite				1·8
Calcite				·9
Apatite				·6
				98·8

The second type of chlorite occurs as small fibres within the former felspar areas. In certain optical properties this type differs from the chlorite replacing carbonate but transitional varieties are found. The fibres in all cases have positive elongation. The intermediate refractive index again lies between 1·60 and 1·61 but the birefringence is less, being approximately ·010. In colour the chlorite replacing felspar is lighter green than the chlorite, replacing carbonate but Z is again a darker green than X. The differences in properties between the chlorite replacing felspar and that replacing carbonate are not great, and are such as might be expected to result from a somewhat greater amount of iron in the chlorite after carbonate.

From the analysis (column A, Table I) of the final chloritic alteration product the composition of the two types of chlorite together, may be estimated. In Table II after appropriate amounts of the oxides have been allotted to the other minerals of the rock, the remaining FeO, MgO, CaO, Al_2O_3 with silica and water, have been calculated into the theoretical chlorite molecules given by Winchel [1926, pp. 283–300]. Since we are dealing here with the analysis of a rock and not of pure chlorite, the only check on the correctness of the assumed component molecules of the chlorite is given by the amount of water. The theoretical amount of water required is 7·94 per cent ; the amount driven off from the rock above 105° C. is 7·75 per cent. A chlorite having this composition should, according to Winchell [1926], be named diabantite. The calculated percentage composition of the chlorite is given under E, Table I, and if, in this form, the analysis is compared with diabantite from a diabase sill at Westfield, Massachusetts, analysed by Shannon [1920, p. 399], there is found to be a moderate agreement. It is noteworthy that the diabantite from Westfield, Massachusetts, has a very similar manner of occurrence to that from the Whin Sill being found in a diabase where hydrothermal action was suspected. Some of the properties assigned to diabantite by Winchell and Shannon differ from those found for the chlorites in the specimen of altered Whin Sill from which the analysis was made. There is a marked discrepancy in the birefringence and the optical axial angle, but on the other hand the average refractive index is in close agreement. A considerable variation in optical properties among the chlorites developed by the hydrothermal alteration of the Whin Sill has been found, but their optical properties will not be given as no analyses indicating their composition have been made.

Variation from the Normal Transition.

The sequence in which the minerals are replaced by the hydrothermal metasomatism has been found to be invariable, but the alteration sometimes does not proceed so far as is indicated in Fig. 3, and sometimes complications are introduced by the partial alteration of the plagioclase to a micaceous mineral. Sections from about 10 feet below the top of the Sill near Winch Bridge (Locality 2) show, near the limit of alteration, the normal sequence ; but at approximately the stage indicated by 1·5 cm. in Fig. 3 the plagioclase is partly replaced by a micaceous mineral which shows the following characters. The habit is fibrous or platy and the individual crystals are very minute ; the elongation is positive ; the refractive index is lower than that of chlorite, and the double refraction is greater than ·018. The mineral is probably sericite, but this cannot be asserted without an analysis since it has so far been found impossible to distinguish under the microscope between sericite, pyrophyllite, and leverrierite. Holmes [1928, p. 509] has used the name sericite for what is probably the same alteration product of the plagioclase in the High Green dykes. At the most, only about half the plagioclase is replaced by the micaceous mineral, but once this is formed, it is not further changed, and is therefore found in the most altered dolerite. In these same sections of material from Winch Bridge a considerable amount of the albite, which formed the outer zone of the plagioclase, is found to persist, even in the most altered rock immediately adjacent to the joint. In slices which show the persistence of much albite, only one-half to two-thirds of the carbonate after pyroxenes, is replaced by chlorite. The maximum alteration shown by material from Winch Bridge is represented accurately by a vertical line through 3·5 cm. in Fig. 3, except that some of the plagioclase is replaced by the micaceous alteration product. The early joints are well developed in the Cowshill intrusion and again the alteration may proceed only so far as to give a rock containing albite and carbonates or it may go further and give the rock consisting essentially of chlorite and quartz.

On the Occurrence of Hydrothermal Alteration in Small Amounts throughout the Whin Sill.

Sections of the freshest Whin Sill, far removed from the early joints, always show signs of what has been in the past regarded as the result of weathering. The margins and wide cleavage cracks of the hypersthene are invariably indefinite, due to the parallel growth of a fibrous alteration product from the cleavage cracks or the outer surface into the fresh mineral. Extensive alteration of this kind may occur and the fibres may then be identified with the bowlingite, found in the zone of hydrothermal alteration, adjacent to the early joints. In the hypersthene-augite, chloritic alteration products are found, although to a less extent, along cleavage cracks or at the outer margin, and chloritic material generally occurs in the major cleavage cracks of plagioclase. Micaceous alteration of the plagioclase is also very widespread and its extent is frequently considerable. Finally small patches of carbonate, presumably from the decomposition of the pyroxenes, occur sporadically in the interstices of the other crystals. The minerals which give any slice of the Whin Sill a weathered appearance are the same as those which result from the action of the hydrothermal solutions present in the early joints. The effects of the hydrothermal solution are intensified in the walls of the joints and the alteration products occur in sufficient amounts to be accurately identified, but the similarity of the alteration products, developed throughout the Whin Sill by the incipient alteration of the various minerals, indicates that they are also the effects of hydrothermal solutions, of the same composition as those which collected in the early joints. Evidently small amounts of the hydrothermal solutions did not escape into the early joints, but remained in the main mass of the dolerite, in the interstices and early formed cleavage cracks, and there effected a similar alteration as the solutions in the early joints.

The Composition and the Manner of Origin of the Hydrothermal Solutions.

To enable an estimate of the gains and losses during metasomatism to be made, constancy in the amount of Al_2O_3, during the formation of the chloritic alteration product, will be assumed. Small amounts of chlorite and of a zeolite may occasionally be observed among the calcite and quartz filling the early joints so that the assumption of no migration of Al_2O_3 must be regarded only as an approximation. Making the assumption, however, significant losses are found to occur in the amounts of SiO_2, CaO, Na_2O, and K_2O and significant gains in the amounts of FeO, MgO, and H_2O (see Table I, columns C and D). Analyses of the rock at different distances from the joint would have given different gains and losses. From the minerals present at 3·5 cm. (see Fig. 3), which corresponds to the extreme hydrothermal alteration product in some cases, it may be deduced that there has been a smaller loss of alkalies and a significant gain in CO_2 as well as H_2O. The occurrence of pyrites at one stage in the alteration shows that H_2S must also have been introduced. The active hydrothermal solutions must have been aqueous and contained CO_2 and H_2S.

The solutions, which at a late stage filled the joints and produced the hydrothermal alteration of the walls, formed at one stage part of the homogeneous Whin Sill magma. It is necessary therefore to offer an explanation of how the hydrothermal solutions, which had been uniformly distributed throughout the magma, became concentrated in the early joints. The work of Niggli [1920] and others on the volatile constituents of magmas shows that the cooling of a normal magma is frequently complicated by the separation of a gaseous phase. If this is postulated in the case of the Whin Sill, the gaseous phase would make its appearance when the primary minerals of the Whin Sill had finished crystallizing and the volatile constituents had become highly concentrated. It would be at this stage, when the dolerite was completely solid and yet at so high a temperature as to be unable to stand any considerable tensional stress, that the early joint system was established. In a discussion of Dr. G. W. Tyrrell's paper on "Dolerite-Sills containing Analcite-Syenite in Central Ayrshire" [1928, p. 568], Mr. E. B. Bailey expressed the opinion that some of the early jointing may be the direct result of the high pressures developed in a magma at the last stage of crystallization. Whatever the origin of the joints may be, the gases, produced within the dolerite, would escape into the spaces formed by the early jointing, until the gaseous pressure in the joints equalled the pressure within the main mass of the dolerite. Under the moderate external pressure of hypabyssal intrusions, the bulk of the volatile constituents would, in this way, become concentrated in the early joints as a heavy gas. With falling temperature the heavy gas would ultimately condense and give a hydrothermal solution.

A PRELIMINARY EXPLANATION OF THE TRANSITION ADJACENT TO THE EARLY JOINTS.

The transition between normal dolerite and the hydrothermally altered material bears some resemblance to the transition to white whin already described and a similar explanation may be attempted. In this case, however, such an explanation is complicated by the steady fall of temperature during the metasomatism. A change in temperature would not only affect the stabilities of the various minerals, but, with much reduced temperature, the rate of reactions compared with the time available, might become so slow as to allow of the persistence of minerals beyond their true range of stability. The explanation of the transition is also complicated by variations in the composition of the active solutions, for the cooling dolerite would, to some extent, behave as a closed system and the reactions taking place in the walls of the early joints would therefore produce a change in the composition of the solutions in the joint. Besides these complications, a preliminary explanation is necessary of how a solution, which had been derived from the interstices of the magma, could attack, at a later stage, the minerals with which it was formerly in equilibrium. In order to produce alteration of the dolerite by inward diffusion of the constituents added during metasomatism and outward diffusion of the waste products of the reactions, the solution in the joint must be a *source*, or place of high concentration for the constituents added, and a *sink*, or place of low concentration for the constituents removed. Whether the solution which first accumulated in the joints be assumed gaseous or liquid it would necessarily be saturated and cooling would result in precipitation of material. It could not, in general, act as a sink for the waste products of reactions between the hydrothermal solutions and the minerals of the joint walls.

Niggli [1920 and Grubenmann and Niggli, 1924, p. 276, for a generalized phase diagram] has shown by analogy with systems that have been experimentally treated, that in the case of those natural magmas which yield a gaseous phase during cooling, there is a sudden increase in the solubility of the silicates when the gaseous solution phase condenses to a liquid. If the hypothesis of the formation of a gaseous phase during cooling is accepted in order to explain how the early joints became filled with a hydrothermal solution, then the increase in solubility when the vapour phase condenses to a liquid, will explain how the concentration of the substances in the solution in the joint is reduced to a level, sufficiently low to enable the solution to act as a sink for the waste products from metasomatic reactions taking place in the joint walls. The diagram by Grubenmann and Niggli [1924, p. 276] shows that, before the re-formation of the liquid phase, the gaseous solution in the joints would remain saturated during cooling. Most or all reactions with the walls would therefore be inhibited, but, if any were not, the amount of such reactions as depended on transport by diffusion would be small because the solubilities of the silicates in the gaseous solvent is small. When, at some lower temperature, the gaseous solution condensed, the liquid solution formed would no longer be saturated and it would become a sink for the waste products from the decomposition of the minerals of the joint walls, such as sodium and potassium silicates, and calcium carbonate. Since the solubilities would be greatly increased, diffusion, which was made possible by the establishment of a sink, would at the same time be made an effective agent of transport because of the steeper concentration gradient due to the increased solubility.

No direct evidence seems to remain unobliterated by later changes, of the existence of the gaseous solution phase but there is one piece of evidence, from the intrusion of dolerite at Cowshill in Weardale, for the stage in the cooling down at which the chloritic alteration took place. As will be shown later, earth movement was in progress at Cowshill during the intrusion and cooling of the dolerite and a specimen has been found showing shattering of the walls of an early joint, subsequent to the chloritic alteration of the joint walls. The cracks in the fractured joint wall are filled with calcite, quartz, and prehnite but the boundaries of the fractured blocks, whether they consist of chloritic alteration product or unaltered dolerite, are completely unaffected by the later solution which deposited the calcite, quartz, and prehnite. The chloritic alteration was produced at an early stage when active metasomatizing solutions existed. The fractures in the joint walls were filled later by a solution which was, from the evidence of the prehnite, a true hydrothermal solution of the dolerite but which was unable to effect any metasomatic alteration, presumably because it was saturated.

It has been shown that, at a certain stage in the cooling of the Whin Sill, the same general conditions for metasomatism seem to have existed as were postulated for the formation of white whin and an explanation along the same lines may therefore be attempted. The undersaturated solution, as soon as it was formed by condensation of the gaseous phase, would begin to dissolve and decompose the minerals of the joint walls. Pyroxenes would be decomposed to carbonates which would react to form chlorite with some of the alumina simultaneously liberated by the decomposition of felspar. Under the conditions of the metasomatism chlorite was apparently the least soluble product that could be formed by all possible double decompositions in the rock. Owing to the precipitation of chlorite the reaction would soon begin to take place in the capillary openings between the newly formed chlorite and the unaltered minerals, and the substances which were not precipitated as chlorite, mainly $CaCO_3$, Na_2CO_3, K_2CO_3, and SiO_2, would rapidly increase in concentration in the confined space of the capillaries. From this stage onward, diffusion and the law of mass action would control the decomposition of the minerals of the dolerite. Thus the rise in concentration of $CaCO_3$, Na_2CO_3, and K_2CO_3 would eventually stabilize the orthoclase and plagioclase and continued decomposition of the felspars would occur only as diffusion reduced the concentration of the waste products below the equilibrium concentration required by the law of mass action.

One general feature is shown by the transition to the chloritic alteration product, which is not well shown in the transition to white whin, namely the replacement of a mineral by another which is itself replaced at a later stage. Thus the hypersthene-augite and the bowlingite are replaced by carbonate which, nearer the joint, gives place to chlorite, simultaneously with the decomposition of the felspars. Replacement of the carbonate by chlorite only occurs where the concentration of such waste products as $CaCO_3$, Na_2CO_3, and K_2CO_3 is low enough to allow of the decomposition of the felspars. Alumina may then migrate as far as the carbonate areas where it is precipitated as chlorite. At the same time, iron and magnesium carbonates migrate into the felspar areas, again with the precipitation of chlorite. There is sufficient difference between the chlorite replacing carbonate and the chlorite replacing felspars to allow of their being distinguished, but the details of the original dolerite texture are destroyed. From the first, the carbonate contains a small amount of chlorite, probably formed from the alumina which is present in the pyroxene to the extent of about 5 per cent. [Teall, 1884, p. 648]. Alumina would not be required n the decomposition of pyroxenes to serpentine but apparently pure serpentine was unstable under the conditions of the hydrothermal metasomatism while chlorite, although considered to contain serpentine in solid solution, was stable. It is interesting to note that at the low temperature of formation of white whin the alumina of the dolerite formed kaolin and mica, while, at the higher temperature of the hydrothermal metasomatism, chlorite was the stable aluminous mineral. Friedel and Grandjean [1909, pp. 151–4] showed that a chlorite was the chief mineral formed, though only in small amounts, when a diopside, containing a low percentage of Al_2O_3, was heated at 550–70° C. with a soda solution. The conditions of the experiment resemble to some extent those which must have existed during the hydrothermal metasomatism of the Whin Sill.

During the course of the metasomatic reactions the solution in the joints must have become modified in composition by the increase n the waste products of the reactions. Changes would proceed in this direction, until the solution could no longer act as an effective sink, when metasomatism would cease. Hydrothermal alteration products have been described above in which the extreme product of alteration, immediately adjacent to the joints, contained unchanged albite in abundance and carbonates. This is to be accounted for by a higher concentration of alkalies in the metasomatizing solutions which would cause the stabilization of albite and would also tend to precipitate calcium and magnesium carbonates. Convection would be expected to cause some circulation of the solution n the joints and in this way a solution with a high content of alkalies, as a result of metasomatism, at one part of the joint system, might reach another part where it would only be able to effect a partial alteration. Sufficient cases have not been examined to prove any significance in the distribution of this incomplete metasomatism but, it may be noted that all examples found came from near the top of the sill. After the waste products had become sufficiently concentrated in the solution to inhibit further reactions, continued cooling would eventually cause the crystallization of the calcite and quartz which fills the early joints. A small part of the alkalies, liberated by the metasomatism, may be accounted for by the zeolites, which are rarely found among the calcite and quartz of the early joints, but the bulk of the alkalies must have escaped from the system into the surrounding rocks. In one case the subsequent history of the alkaline solutions may be traced. Hutchings [1895, p. 124; 1898, p. 78] has described the replacement of detrital quartz grains in a shale 80 feet below the Whin Sill at Falcon Clints, by a micaceous mineral, and it has previously been suggested [Wager,

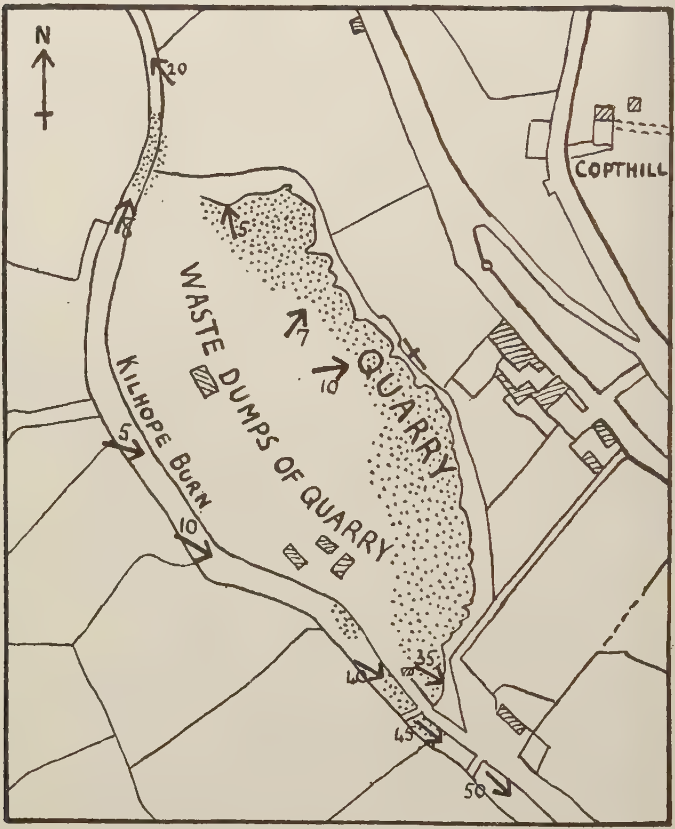

FIG. 4.—Sketch-map of the phacolith of dolerite exposed in the road metal quarry at Cowshill, Weardale. Stippled areas are dolerite. Dip arrows indicate the dips of the adjacent Yordale beds. Scale 18 in. = 1 mile.

1928] that the replacement was the result of reactions between alkaline solutions and the kaolin and detrital quartz of the shale. The origin of the alkaline solutions may now be traced, with some certainty, to the late stage hydrothermal solutions of the dolerite, which had become enriched in alkalies, as a result of metasomatism.

PHENOMENA OF THE HYDROTHERMAL STAGE IN THE COWSHILL INTRUSION.

At Cowshill in Weardale, about 400 yards north-east of the Burtreeford line of disturbance, there is a small intrusion of Whin Sill magma, which is well exposed in a road metal quarry. The Burtreeford disturbance which crosses the upper parts of Weardale and Teesdale, here runs approximately north-north-east and south-south-west some little way beyond the S.E. limit of the sketch map of the intrusion (Fig. 4). The dips of the Yoredale beds, which are exposed in the stream, increase to 55° as the actual fault line is approached, and the Burtreeford line of disturbance seems here to be a flexure broken along its septum. The intrusion of dolerite occurs at the crest of a pitching anticline. At the centre of the quarry the dolerite is over 100 feet thick; at the north-west end of the quarry it is only about 50 feet thick and in the stream to the north-west its thickness is even less. There is an equally marked thinning to the south-east and, as far as can be determined, the intrusion also thins when traced along the crest of the anticline in a direction opposite to that of the pitch, that is to the south-west. The form of the intrusion is that of a pitching phacolith and its relation to the important line of the Burtreeford disturbance, suggests that the intrusion is a true phacolith, produced by general earth pressures, acting at the time of intrusion. The conception of the intrusion as a phacolith is confirmed by the significant distribution within the mass of a late stage differentiation product. The patches of differentiate, which vary from microscopic dimensions up to masses of many cubic yards, occupy cavities, approximately half way between the upper and lower surfaces of the intrusion, near the letter Y of "*quarry*" which is in the larger print (Fig. 4). The situation is just such as would be expected, were they caused by a renewal of the movement which produced the phacolith. The Cowshill intrusion thus offers conclusive evidence of important earth movement contemporaneous with the intrusion of magma of the Whin Sill type.

The material partly or completely filling the cavities, produced by the earth movement, is largely of calcite with a subordinate amount of quartz in well shaped crystals. This material is essentially the same as that filling the early joints and the similarity of its origin is confirmed by the concentric arrangement, round the boundaries of the irregular cavities, of hydrothermal alteration similar to that which is characteristic of the walls of the early joints. Only rarely, however, in the cavities of the Cowshill intrusion may the effects of hydrothermal metasomatism be exactly paralleled with that adjacent to the early joints. The largest mass of hydrothermal calcite rock, which fills three-quarters of a cavity of many cubic yards in volume, consists of isolated, well-shaped, crystals of quartz, albite, and sphene, and patches of chlorite (after some mineral as yet unidentified) arranged poikilitically within large crystals of calcite. The lower margin of this cavity consists in places of a rock, coarser than the typical dolerite, and made up of large albite crystals, chlorite, pyrites and anatase. In other places the rock forming the boundary of the cavity consists of lath-shaped albite crystals of approximately the same size as the plagioclase crystals of the normal dolerite, but crowded with inclusions of chlorite; calcite and chlorite occur interstitially as though they replaced augite; orthoclase and quartz are absent. At the boundary of this rock and the hydrothermal calcite rock, anatase was observed in the process of replacement by sphene. Round many of the smaller masses of hydrothermal calcite rock, the transition from normal dolerite includes a stage in which the felspar consists of albite, which is replaced by chlorite nearer the cavity.

At Cowshill a continuous series of rock types have been produced between the stage at which segregation veins form and the hydrothermal stage. Segregation veins in quartz-dolerites have frequently been described especially from intrusions in the Midland Valley of Scotland, and they occur, although more rarely, in the Whin Sill. At Staple Rock near Winch Bridge in Teesdale, for example, a thick sheet of sediment, which formed the roof of the sill, has broken away and sagged into the dolerite. This produced minor disturbances during the early stage of the cooling of the dolerite and pink segregation veins are occasionally found about the sinking edge of the sheet of sediment. Like some of the Scottish types of segregation veins, they consist of acid plagioclase, with subsidiary orthoclase and quartz. At an early stage in the Cowshill intrusion, earth movement may well have produced cavities which could be filled with the residuum of the liquid magma stage. The coarse albite rock, which occurs below the largest mass of hydrothermal calcite rock, may have originated in this way. There seems evidence, however, that in some cases albite has been produced by the action, of soda solutions on a more basic plagioclase. The early joints in the Whin Sill were not opened until the dolerite could support moderate tensional stress and the mesostasis had completely solidified; therefore there is no differentiation by filter-press action at the liquid magma stage and the hydrothermal solutions act, without complication, on the undifferentiated dolerite. At Cowshill much detailed work remains to be done to disentangle the results of filter-press differentiation from the superimposed hydrothermal metasomatism.

SUMMARY OF PARTS I AND II.

Two types of metasomatism in the Whin Sill dolerite are described :

(*a*) Alteration to *white whin* by lead vein solutions.

(*b*) Hydrothermal alteration by juvenile solutions.

(*a*) In the alteration to white whin, the pyroxenes are replaced by carbonates ; the felspars by mica and kaolin ; the ilmenite by anatase ; the original quartz is increased by a small amount and the apatite remains unchanged. The sub-ophitic texture of the dolerite is accurately preserved.

On the assumption of no gain or loss of Al_2O_3 the metasomatizing solution is shown to have been essentially an aqueous solution of CO_2. Iron, which is largely removed during metasomatism is reprecipitated in contraction cracks and in the lead veins.

A transition between the white whin and the unaltered dolerite, due to successive replacement of the various minerals, is described. The transition is used to show the importance of the parts played by diffusion and the law of mass action, and to confirm and extend Goldschmidt's *principle of minimum concentration* in metasomatism.

(*b*) An early joint system is described along the walls of which there has been alteration by hydrothermal solutions.

A transition, due to successive replacement of the various minerals, is again found between the normal dolerite and a chlorite-quartz-rock, the extreme type of hydrothermal alteration product. During the alteration, hypersthene is first altered to bowlingite, which is described in detail.

Incipient alteration found throughout the Whin Sill and usually ascribed to weathering is shown to be of hydrothermal origin.

The active hydrothermal solution is believed to have been aqueous, with CO_2, and a small amount of H_2S, dissolved in it. It is suggested that the joints were filled at a high temperature with a gaseous phase which makes its appearance at the end of the solidification process, and that condensation of the gaseous phase produced the hydrothermal solutions.

A *sink* for the waste products of metasomatic reactions is shown to be produced by the increased powers of solution when the gaseous phase condenses to a liquid. The transition is tentatively explained in the same way as for the white whin.

Special phenomena, extending continuously from the liquid magma stage to the hydrothermal stage, are described briefly from the Cowshill intrusion, where the unusual effects are correlated with minor earth movements occurring throughout the cooling.

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REVIEWS.

The Earth: its Nature and History. By E. Greenly. pp. 54, with 11 figures. London: Watts and Co., 1927. Price 1*s*.

THE author of this charmingly written little book has indeed undertaken an appalling task. To write an introduction to geology in 54 pages, and very small pages at that, requires a power of selection and compression granted to few writers, yet he has produced a work which will do much to stimulate an interest in the science, and to show that geology is not, as so many seem to think, and our museums would lead them to believe, a mere catalogue of dry bones, but a living and an active interest, which can add something to the joys of life. A geologist is often led to reflect that travel amid natural beauties must lose half its pleasure for those who have no idea of the reason and meaning of it all. As an opening glimpse of what earth-forms and earth-history signify to the initiated this book may be strongly commended.

PATTERNS FOR A SERIES OF TWELVE BLOCK MODELS ILLUSTRATING GEOLOGICAL STRUCTURES: with descriptive notes. By F. SMITHSON, Ph.D., F.G.S. London: Thomas Murby and Co. New York: D. van Nostrand, 1929. Price 4*s*.

THIS publication consists of a series of very clearly printed geological diagrams so arranged that they can be cut out and stuck together in the form of solid models, representing the usual block-diagrams of the text-books in the three-dimensional form. The structures illustrated are well chosen and the models, when constructed, cannot fail to be of great use to elementary students of geology, enabling them to visualize the real nature of the commoner types of faults and folds. One of the greatest difficulties of teachers has always been to get students to think in three dimensions instead of two; hence the greatly increasing use of models of all kinds.

The publishers undertake to supply cardboard blocks on to which the patterns can be gummed, and also the whole set mounted in this way. It may perhaps be suggested that blocks of wood of the same size would be more durable and more generally satisfactory.

THE GEOLOGY OF THE COUNTRY NEAR RAMSGATE AND DOVER. By H. J. OSBORNE WHITE. Mem. Geol. Survey, England. Explanation of Sheets 274 and 290, pp. xxi + 98, 5 plates, and 15 text-figures. 1928. Price 2*s*. 9*d*.

THIS memoir contains a short summary of our knowledge of the concealed formations—Lower Cretaceous, Jurassic, and Carboniferous—based on borings connected with the Kent Coalfield. It describes the Chalk (Turonian and Senonian), well exposed in the coast sections, and gives additional information about inland exposures and the overlap of the vertical ranges of *Uintacrinus* and *Marsupites*. In the account of the Thanet Sands and Woolwich Beds, new exposures of the Thanet beds north of the River Stour are noticed.

The new coloured printed 1 in. Sheets (274 and 290) contain additions and corrections by H. G. Dines and F. H. Edmunds.

THE GEOLOGY OF THE COUNTRY AROUND WOODBRIDGE, FELIXSTOWE, AND ORFORD. By P. G. H. BOSWELL. Mem. Geol. Surv. England and Wales. Explanation of Sheets 208 and 225, pp. ix + 80, 15 text-figures, 2 plates. 1928. Price 2*s*. 6*d*.

THE Memoir, which deals with an approximately triangular area, is largely supplementary to that of Sheet 207 by the same author, which is concerned with the district to the west. Naturally most of the conclusions drawn in the two memoirs are essentially the same. The formations outcropping at the surface range from London Clay to Recent, and include those famous fossiliferous Pliocene deposits, the "Crags". Some mention is also made of the

Chalk, Thanet, and Reading Beds, which underlie the area at no great depth. The Glacial deposits (sands and gravel, brickearth, and Chalky Boulder Clay) are regarded as all belonging to one series of Upper Glacial age. Some interesting examples of buried channels of Glacial Drift are briefly described. Accounts of the petrography of the various beds with the exception of the Glacial and Recent deposits are included. In the chapter on the latter is an interesting summary of the recent coast-line changes. The area is almost devoid of tectonic features. H. D. T.

CORRESPONDENCE.

THE NOMENCLATURE OF FOLD-SYSTEMS.

SIR,—In the review of Krenkel's *Geologie Afrikas* in the March number of the GEOLOGICAL MAGAZINE attention is drawn to the difficulty of finding euphonious equivalents to terms such as Afriziden and Capiden. Like your reviewer, I see objections to the suffix *-īde.* The astronomers and palaeontologists use *-id* as a group suffix, so why not geologists ? For some years I have consistently translated such terms as Dinariden (the cadence of which I sacrifice with regret) by Dinarids. Dinarides will conceivably be pronounced by students as Dinar-īdes (three syllables) or Dinari-des (four syllables) according to choice. It is true that the forms Laramides and Altaides are of fairly long standing, but it is perhaps not too late to plead for Grisonids, Helvetids, and so on, as being easier to say and also to defend on etymological grounds.

I could almost find myself saying " beware the ides of March ! "

Yours faithfully,
P. G. H. BOSWELL.

DEPT. OF GEOLOGY,
UNIVERSITY OF LIVERPOOL.
14*th March*, 1929.

[The Editor would be glad to receive further views on this matter : in his opinion it is desirable that many of these barbarisms should be squelched before it is too late.]

The annual Holiday Course in Economic Geology of the School of Metalliferous Mining at Camborne, Cornwall, will be held this year from 8th July to 16th August, under the direction of Mr. E. H. Davison, B.Sc. This course has now been held for ten years, and has been attended, with much advantage to themselves, by students from the Universities both British and foreign, and by well-known mining engineers and geologists home on leave from many parts of the world. All particulars can be obtained from the Secretary of the School, as above. It may be mentioned that the fee is only six guineas, and that the cost of living at Camborne is unusually low. The plan includes numerous field excursions and affords unrivalled opportunities for practical work, especially on igneous rocks and metalliferous deposits, as well as mapping and surveying.